Mapping of Kabe Watershed Using GIS and Remote Sensing

ILRI in collaboration with Wollo University and UNEP

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Addis Ababa University
Bekele Abebe (Ph.D) and Mickias W.Sellassie

Contents

1. Introduction

ILRI in collaboration with UNEP and Wollo University has run a project "Enhancing communities' adaptive capacity to climate-change induced water scarcity in drought-prone hotspots of the Blue Nile basin, Ethiopia" at Kabe watershed in south Wollo. The goal of this project was to enhance the adaptive capacity of communities and local institutions in drought-prone regions of the Blue Nile Basin, Ethiopia to climate- induced water stress. The project had an aim to develop a pilot site for adaptation to climate through facilitating communities and their institutions and triggering initial impetus to employ integrated water resource use and management interventions, and that also maximize multifunctionality of ecosystems services, through collective action and social learning. Mapping and targeting land and water related interventions in the landscape, was one of the activities of the project. This mapping activity requires GIS expertise and therefore, the main objective of this project was to generate different maps as it's stipulated in the following TOR within the umbrella of the aforementioned project.

2. Terms of reference (TOR)

The following lists of maps were expected to be generated at the end of this mapping project.

1. Watershed/catchment delineation
2. Landuse types/land cover
3. Hydrology/water resources (distribution of springs, wells, rivers...)
4. Soil types
5. Lithological/Structural maps
6. Vegetation types/biomass production
7. Human and livestock population density
8. Agroclamatic zones/altitude

9. Climate change- rainfall and temperature trends/projections
10. Future projections on water and landuse

3. Methodology

Like any other scientific projects, we have followed the following steps to meet the goals and objective of this project:

3.1. **Data Collection:** Different primary and secondary datasets was collected and used during this mapping. This includes satellite images, meteorological datasets, demographical datasets and other ancillary datasets.

3.2. **Data analysis:** After these data sets have been collected, automated and converted to appropriate data formats in a GIS environment, different analysis have been done to these datasets.

3.3. **Data Interpretation:** The results of our analysis were then interpreted accordingly and hence, produce different thematic maps.

3.4. **Verification and validation:** These interpreted thematic maps were verified and validated with different techniques, which includes onsite field ground truthing and model calibration. Repeated reinterpretation was done on these thematic maps so as to incorporate the validation and verification.

See the general work flow diagram below

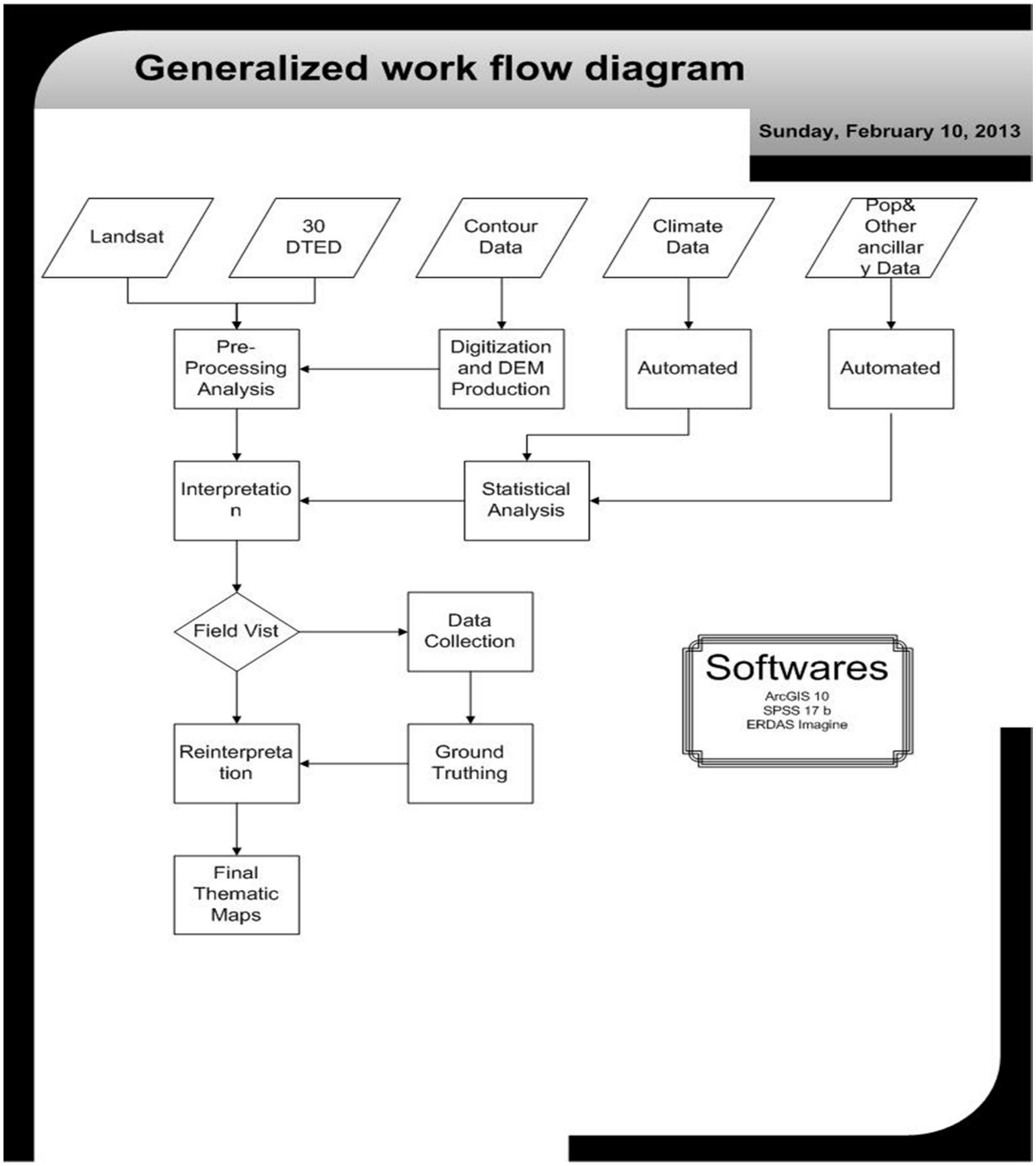


Fig. 1, General work flow diagram

4. Outputs

4.1. Watershed/catchment delineation

The watershed and catchment delineation was done by blending 20m contour with 30 m DTED. Thus, boundaries of Kabe Watershed and the four sub-watersheds (Amanuel, Yewol, Aba Girja and Fortu) in it are delineated effectively using remote sensing watershed delineation tool. These sub-watersheds have an area of 7.675966, 4.234163, 2.862803, and 1.393693 square kilometer respectively.

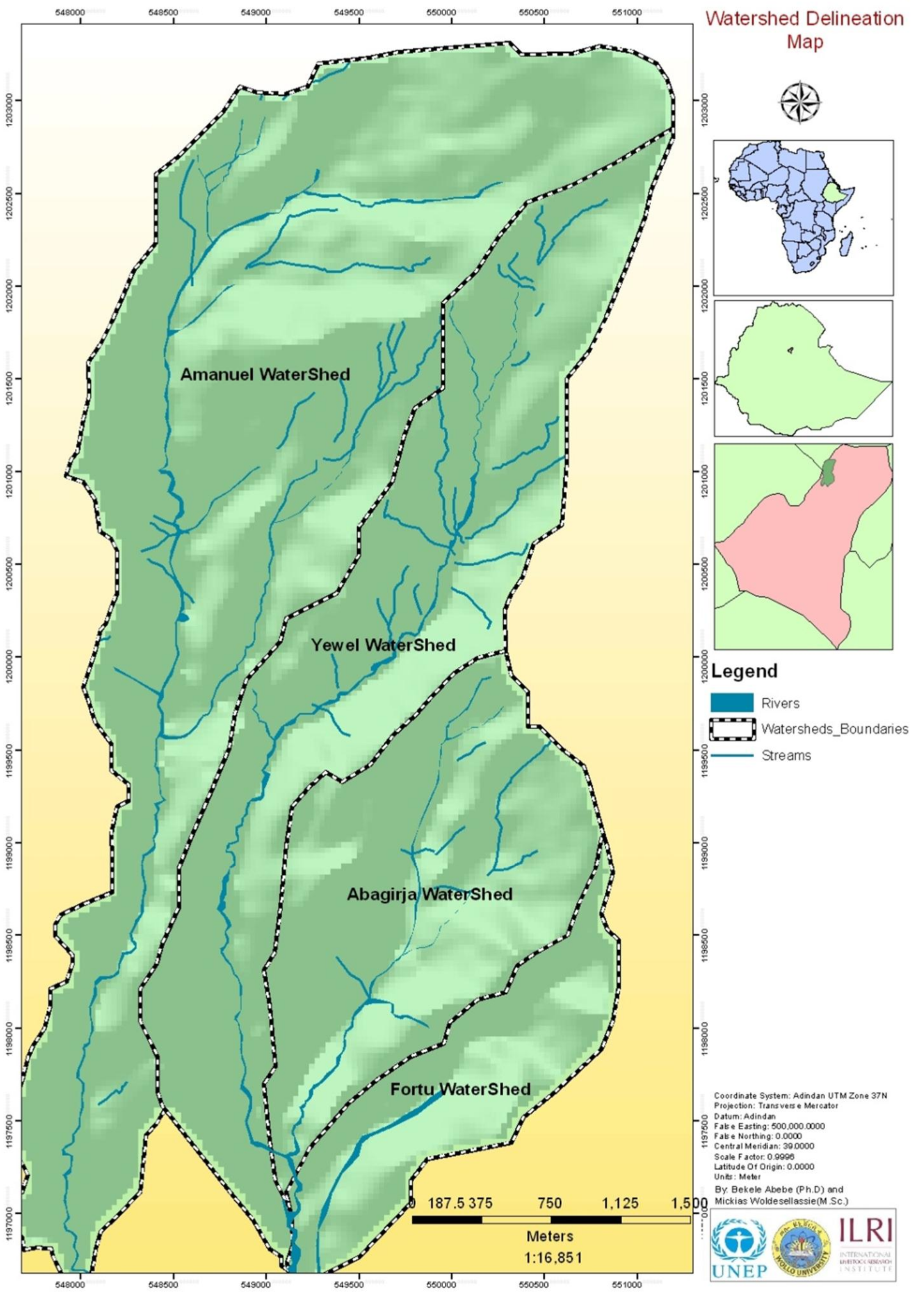


Fig. 2 Watershed Delineation Map

4.2. Landuse types/land cover

Since the area was too small (16.1 sq km) to map from Landsat using the usual classification methods accompanied by error matrix, we were forced to change our approaches to increase the accuracy. The landuse/landcover is thus, mapped from high resolution satellite imagery (i.e. Quickbird imagery with 0.65m spatial resolution). This enabled us to map every land use/landcover with almost 100% accuracy. About 70% of the area is used for agriculture and 15% is a bareland. To increase the productivity of the area, implementation of integrated land management is highly advisable. And hence, an integrated land use and watershed management interventions over this bare land can change the area a lot. Only 2.5% of the area is covered with dense and sparse forest. See the summary table and the map below for the landuse/landcover.

No	Landuse/Landcover	Area (in sq km)	Percentage
1	Settlements	0.656051	4.12411489
2	Agricultural lands	11.327143	71.2054995
3	Bare lands	2.372759	14.915808
4	Grazing lands	0.682907	4.29293901
5	Shrubs	0.449969	2.82862743
6	Sparse forest	0.253567	1.59399108
7	Trees (Eucalyptus)	0.165285	1.03902643

Table 1. Landuse/Landcover statistics

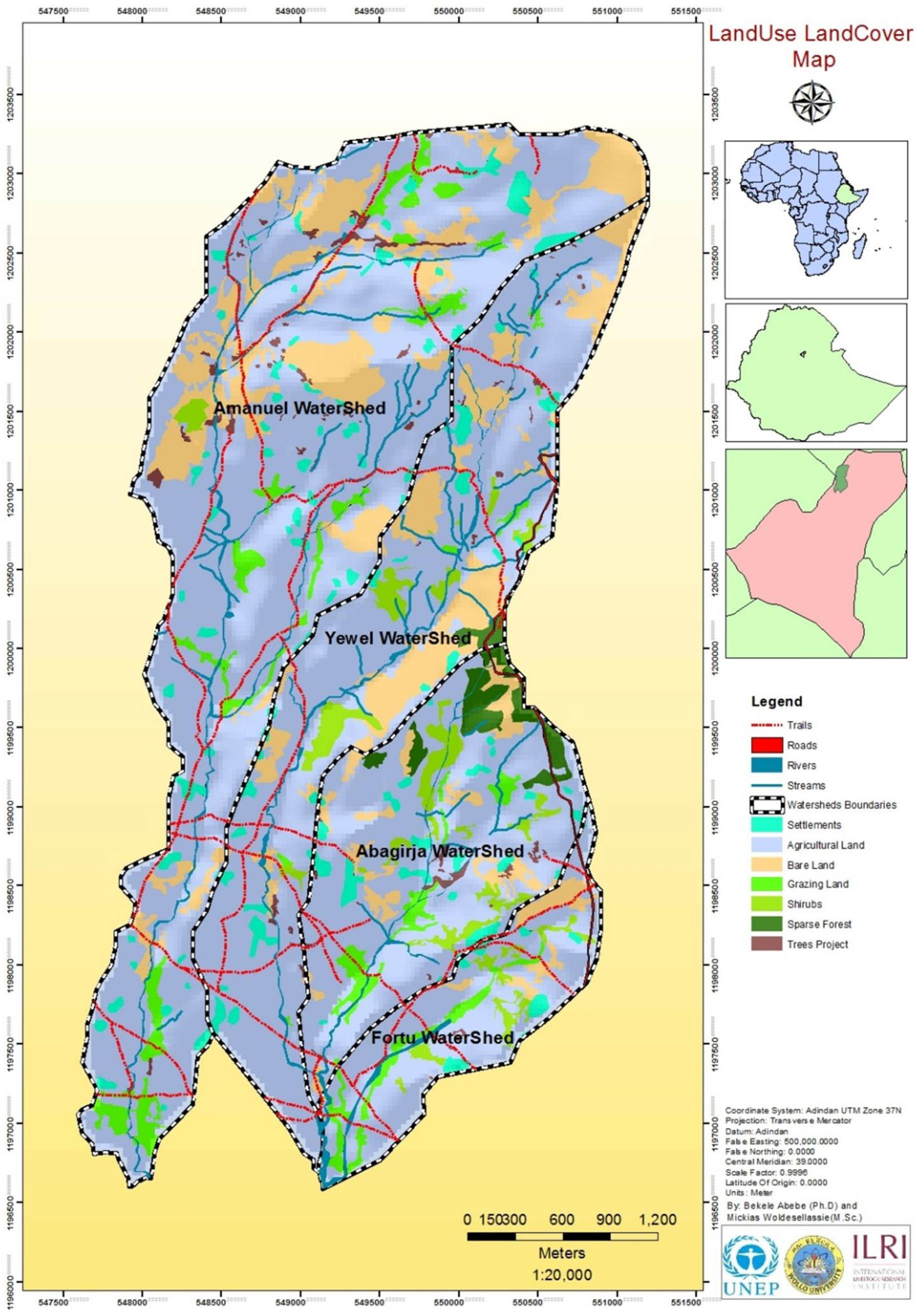


Fig. 3 Landuse/Land Cover Map

4.3. Hydrology/water resources (distribution of springs, wells, rivers...):

The rivers networks are automatically extracted from the DEM and ground truthed in the field. On the other hand, the location of every water resource points (Eg: springs, wells, etc) were collected during the field visit and plotted in a GIS system. Most of these rivers have a dendritic drainage pattern flowing from Northeastern

part of the area to Southwest. Moreover, all of these rivers/streams are tributaries of River Selge. See the tabular data for the water resource site in Annex 1.

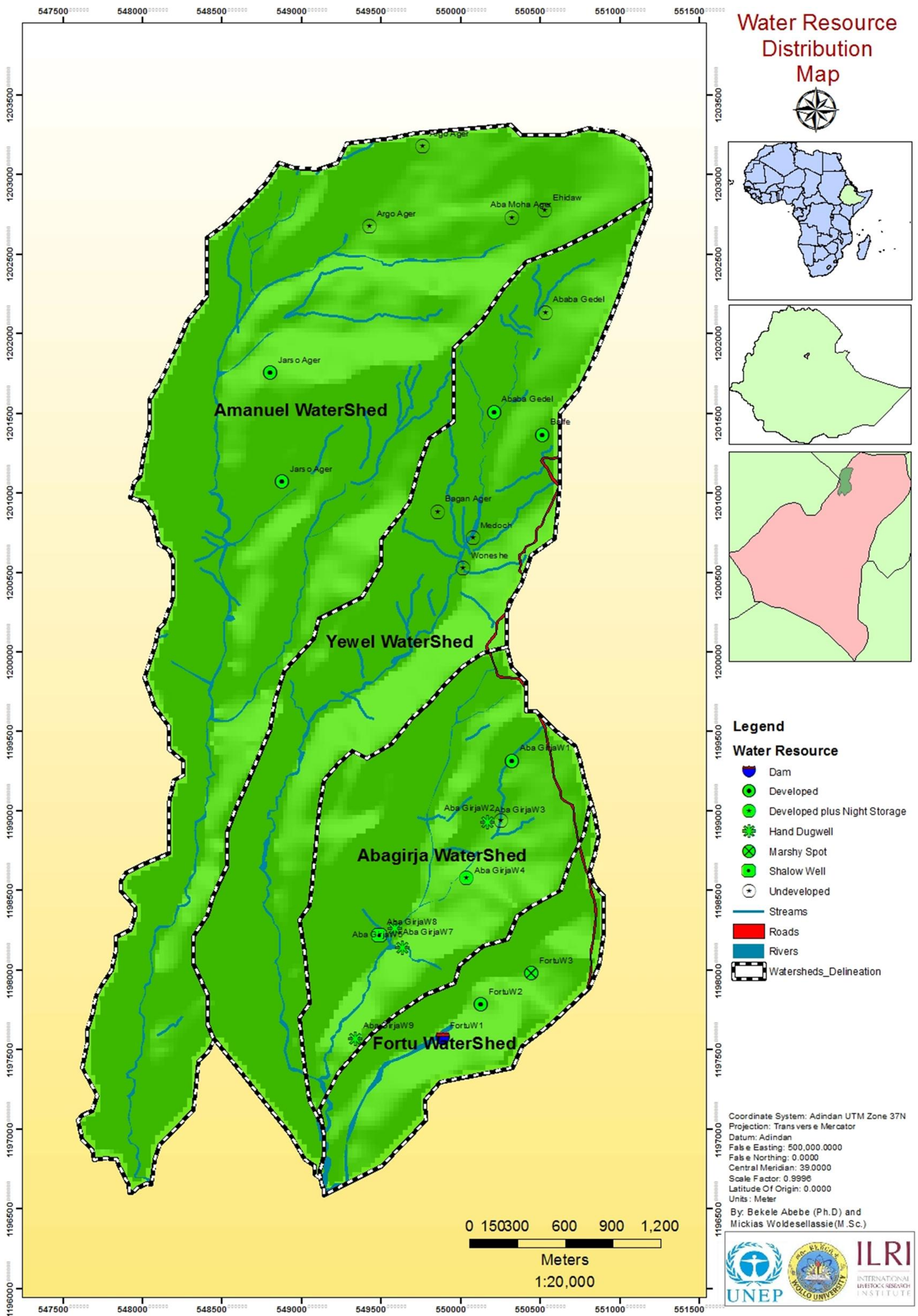


Fig. 4 Water Resource Map

4.4. Soil types

The more or less uniform lithology dominated by basalt has not allowed the development of soil diversity. Besides, the topography, microclimate and vegetation cover do not show variations, making almost all soil forming factors uniform over the area.

Soil mapping was done by merging satellite image interpretation backed by field sampling with additional input from the FAO World Reference Base for Soil Resources (2006). Four major types of soils are mapped in this area, i.e Eutric nitisols, Eutric regosols, Gleyic cambislos and Vitric cambisols. All these soil types are the result of a monotonous volcanic lithology in the area. Among all, the dominant soil type in the area is Gleyic cambisols and found in the western and cetral part of the area. This soil type is known for its slight profile development that is not dark in color. Cambisols are soils at an early stage of soil formation and generally make good agricultural land and are used intensively for agriculture.

On the other hand Nitisols, are soils with a very thick layer of clay accumulation. They are among the most productive soils of the humid tropics. The deep and porous solum and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion. Their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favorably to those of most other tropical soils. Nitisols are planted to plantation crops such as cocoa, coffee, rubber and pineapple, and are also widely used for food crop production on small holdings.

Eutric Regosols are soils consisting of unconsolidated material from freshly deposited alluvium or sand. They are weakly developed mineral soil in unconsolidated materials, found extensively in eroding lands, in particular in arid and semiarid areas and in mountain regions. Traditionally farmers use these soils to grow sorghum, sesame, etc along the nile river.

Continuous agricultural practices and erosion by water and mass movement have prevented the formation of thick soil profiles. This phenomenon is ubiquitous in most parts of the Ethiopia highlands.

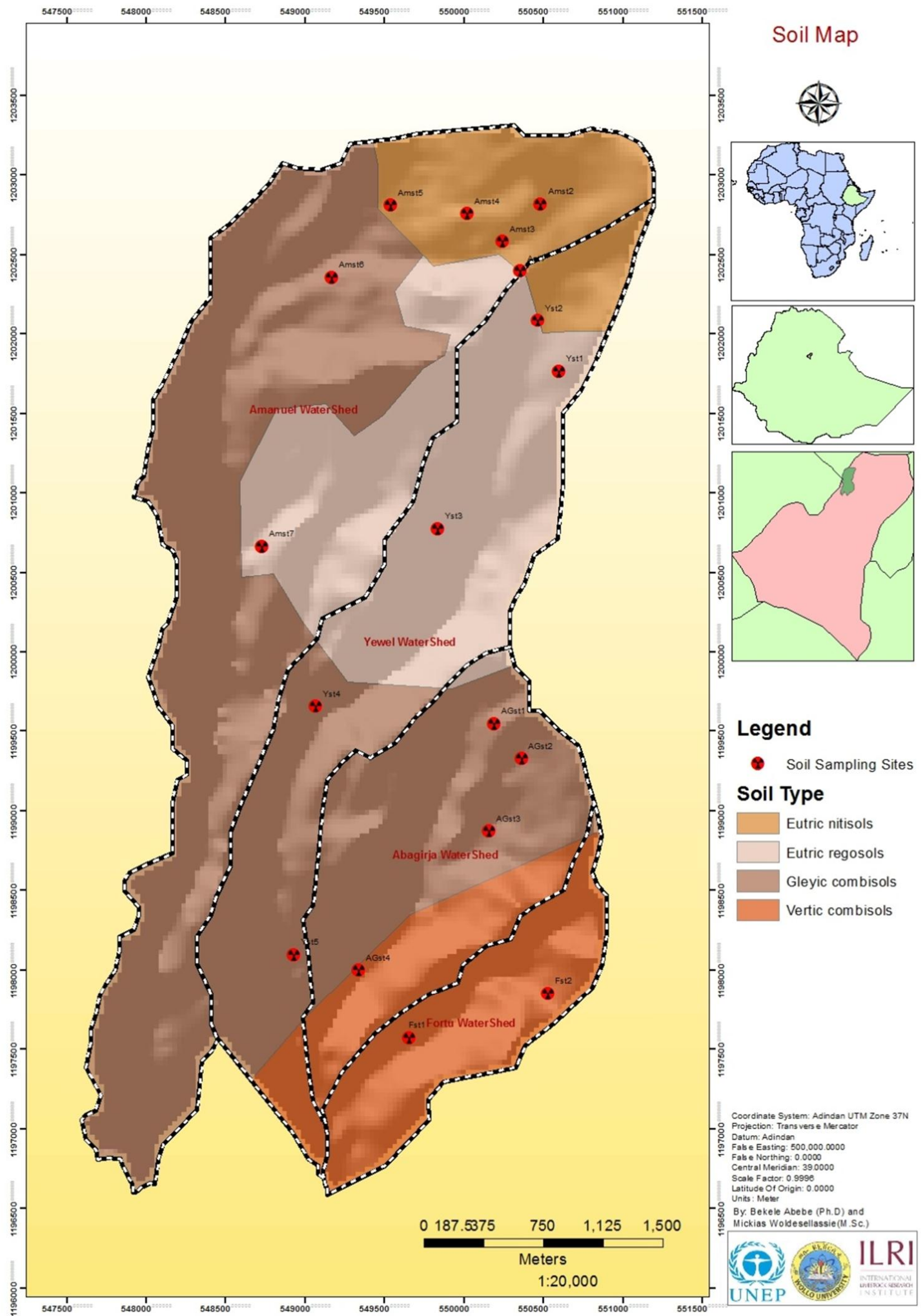


Fig. 5 Soil map

4.5. Lithological/Structural maps

Satellite based lithological mapping and lineament extraction is used to map the geology of the area. The satellite image interpretation is supplemented by field ground truthing. The dominant lithology in the area is monotonous shield volcano.
The oldest rock exposure, in the southern part of the study area constitutes continental flood basalts erupted in the Late Oligocene- Earlo Miocene, mainly between 29 and 30 Ma (Hoffman et al., 1997). Most of the area is covered by Miocene basaltic rocks of the shield volcanoes covering the sub-horizontal flood basalts flows of the plateau. Within the shield volcanic products, small and scattered trachytic plugs form prominent outcrops owing to their resistance to erosion. Alluvial deposits along the small stream courses are the other geologic units in the Kabe area. They comprise alluvial detritus of variable grain size, from which have developed thin soil profiles.
NS, NNW-SSE and NNE-SSW trending lineaments control the drainage pattern. These structure have developed as a result of reactivation of older weakness zones.
These structural trends show the influence of the structural influence of the deformation in the Afar margin to the east. Besides, a few dikes of WNW-ESE orientation cut the plateau and shield basalts.
The lineaments, strike parallel to the topography and hence, act as conduits for ground and surface water in this mountainous area. The dikes, on the other hand are oriented nearly orthogonal to the topographic slope and serve as dams to groundwater. Some springs (e.g. Balfe spring), have developed at points where the dikes block groundwater seeping from the water divide.

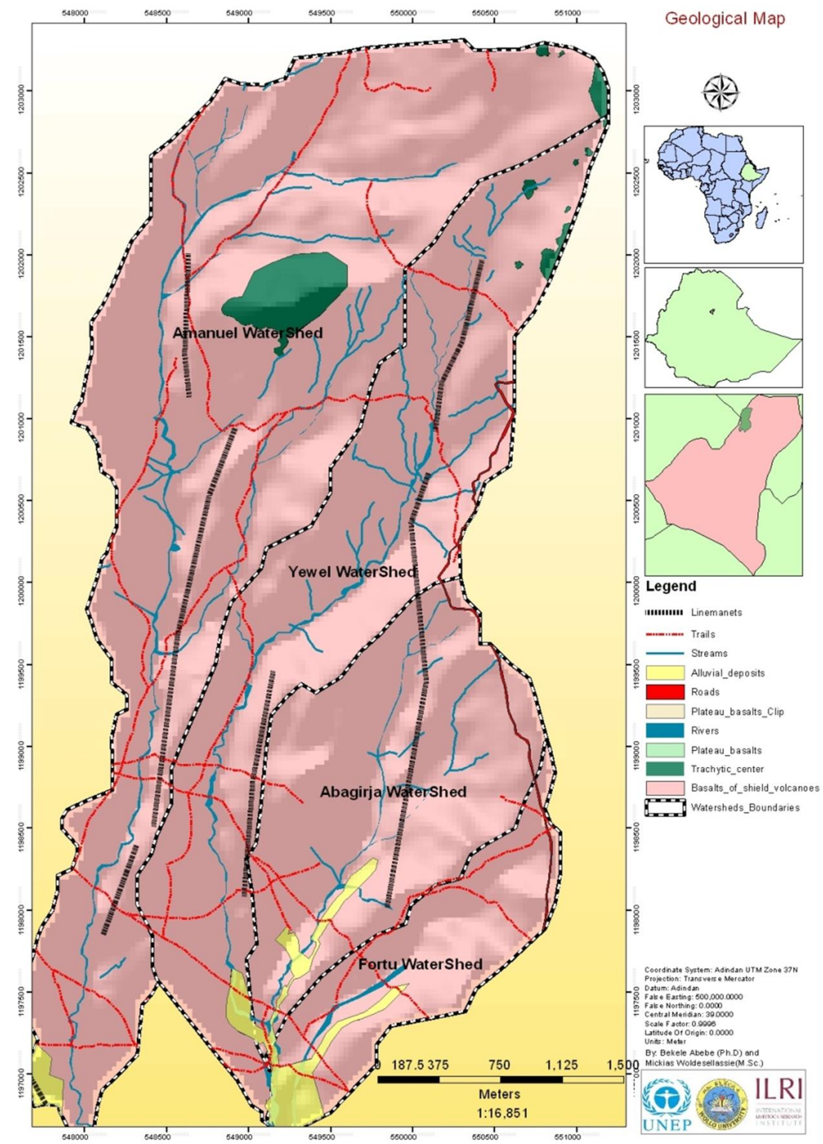


Fig. 6 Geological map of the area.

4.6. Vegetation types

The vegetation types are also mapped from high resolution satellite imageries with high accuracy. Four major types of vegetation are mapped in the area which accounted for about 10% of the total area. Grass land has higher areal coverage relatively followed by shrubs and bushes. See table 2 and fig 7 for summarized vegetation type information.

No	Landuse/Landcover	Area (in sq km)	Percentage
1	Grass	0.682907	4.29293901
2	Shrubs	0.449969	2.82862743
3	Sparse forest	0.253567	1.59399108
4	Trees (Eucalyptus)	0.165285	1.03902643
Total		1.551728	9.75458398

Table 2. Vegetation type map

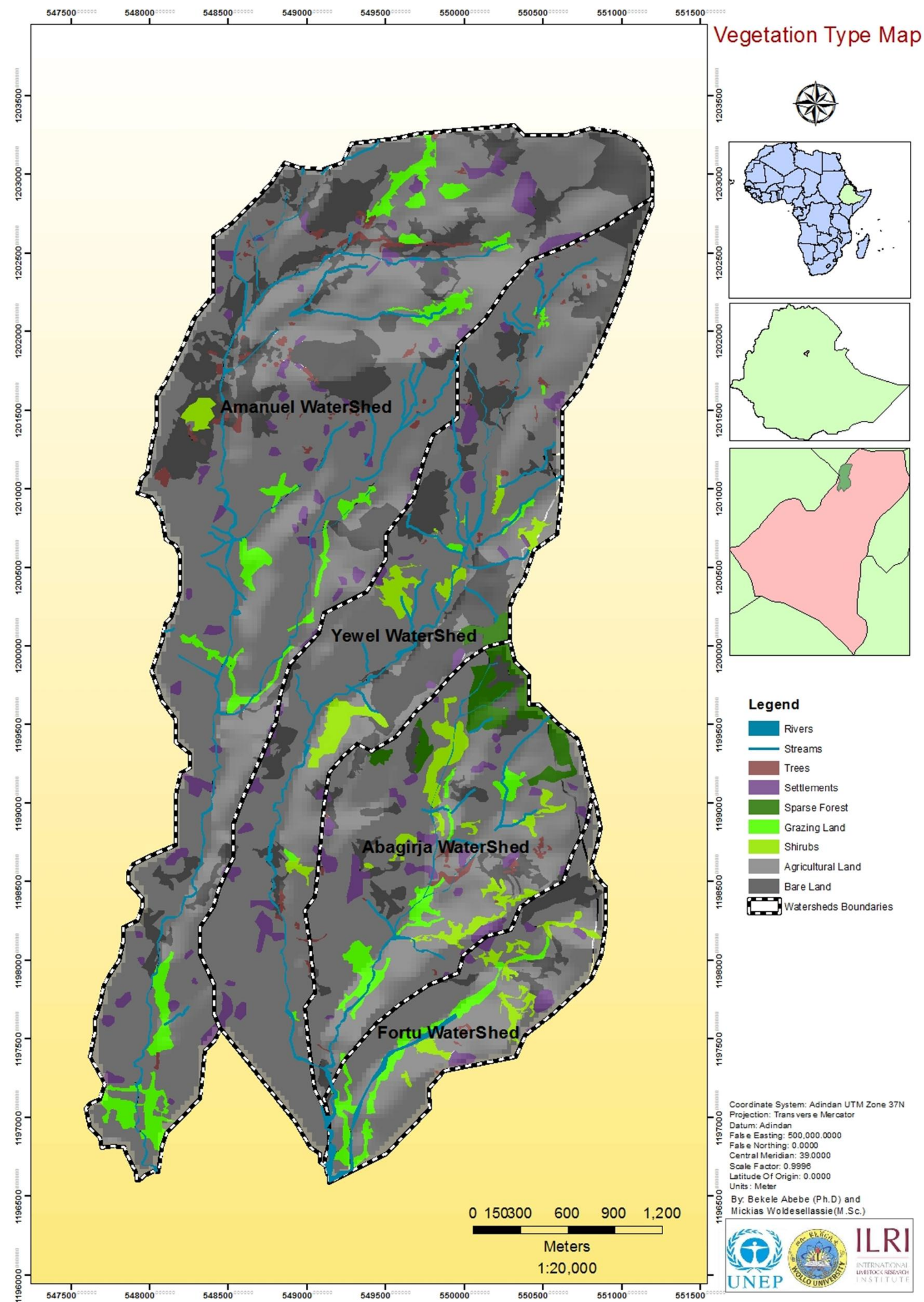


Fig. 7 Vegetation map

4.7. Human and livestock population density:

As it’s mentioned above, the area is too small and falls in one kebele. It’s very difficult to get lower administration unit than Kebele in Ethiopian context. Thus, it can be approached in three ways:

4.7.1. Mapping at watershed level:

It was done by taking into consideration the total population density at the watershed level and its area. This population density map shows Amanuel as densely populated watershed and followed by Fortu, Abagirja and Yewol watersheds respectively. This effectively maps the population density in each watershed, however, it doesn’t tell the variation with in each watershed (See Fig. 8). With the same methodology, population density maps for different animals are also generated. (See Apeendix 1-10)

So, to see better depict the variation with in the each watershed, another approach, which is called Grid based was used.

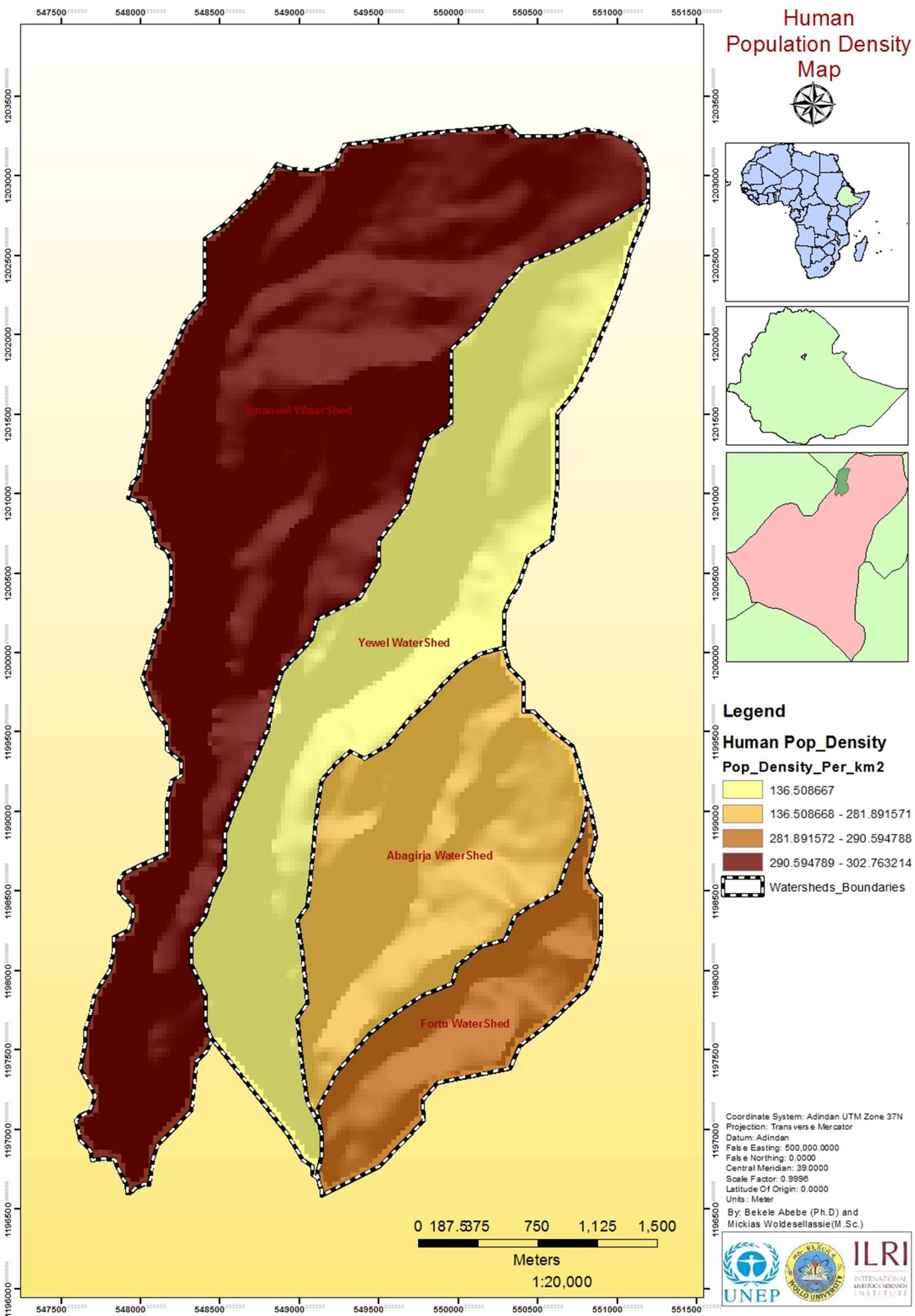


Fig. 8 Human Population map at watershed level

4.7.2. Grid based level:

By dividing the whole watershed with 200m by 200m grid and counting the number of houses from a high resolution satellite images, it's possible to map the variation across and within each watershed. For instance population density of each 200mx200m grid is calculated by counting the number of houses in that grid and multiplied it with 5, assuming that 5 peoples live in every single house. Thus, dividing the product with the area of that grid gives the population density. As it can be seen from the map, specifically the northern part of Amanuel and the middle part of Abagirja watersheds are relatively densely populated (See Fig. 9). However, an expert assumption is still needed to map the livestock as in the same fashion.

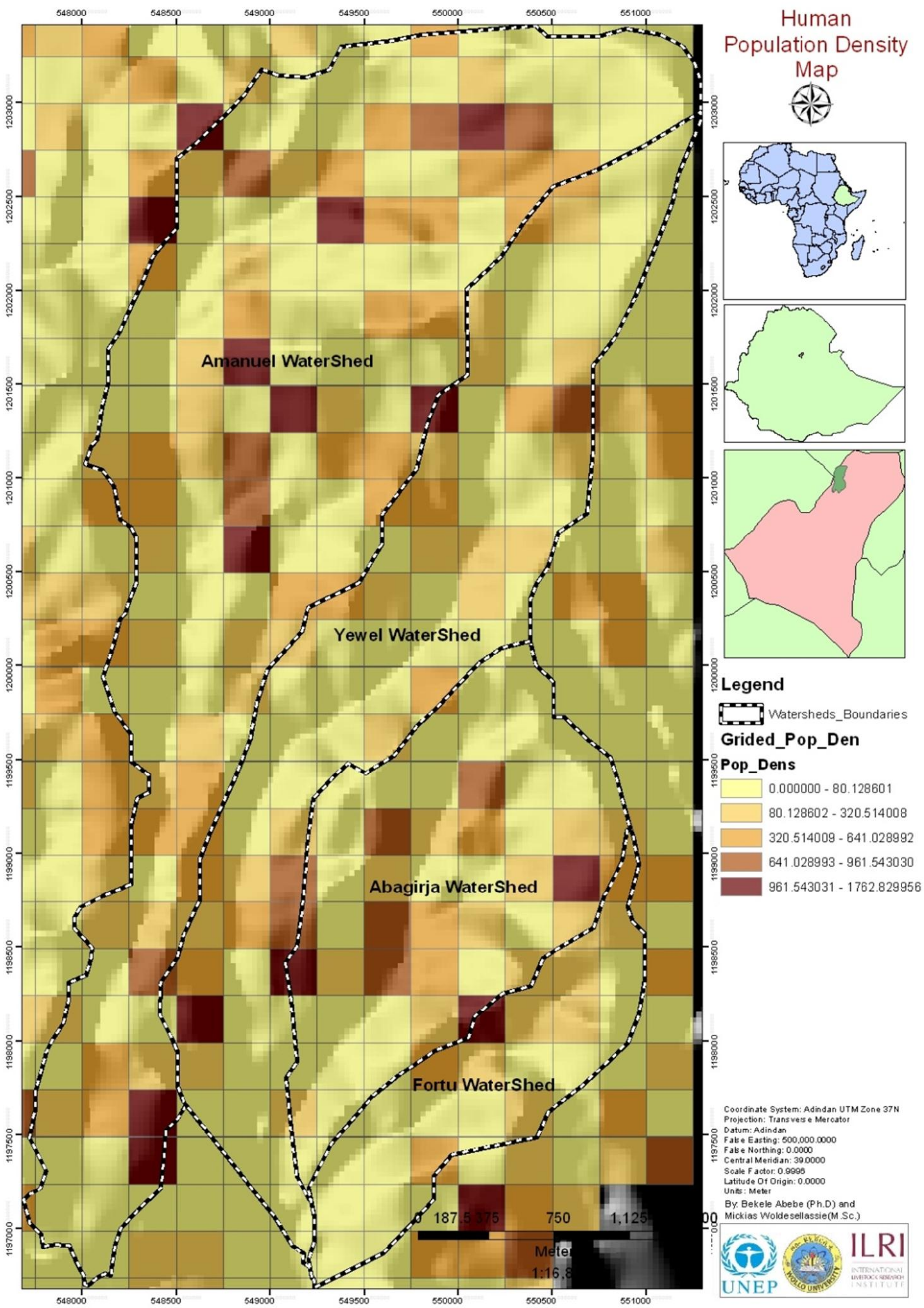


Fig. 9 200mx200m grid based human population density map.

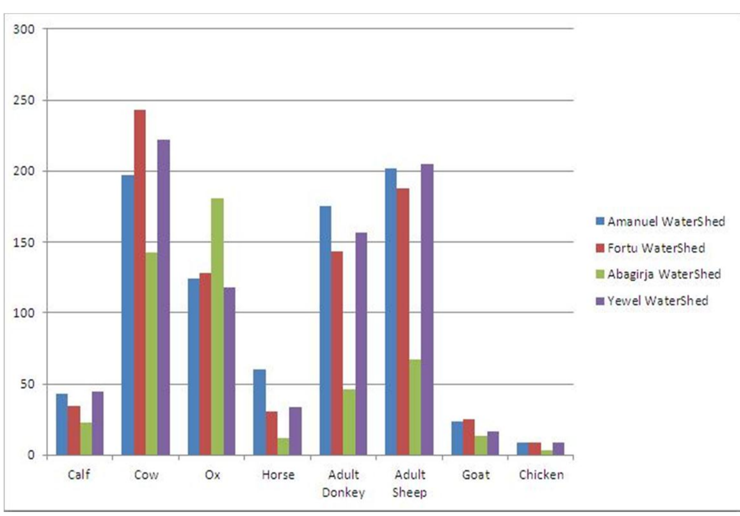
4.7.3. Tropical Livestock Unit (TLU) Representation:

As the name tells, this is applicable only for livestock resources in the area. It provides a convenient method for quantifying a wide range of different livestock types and sizes in a standardized manner. However, data gaps are still being a big challenge to map and represent the livestock resource of the area with TLU. (See the available data in Table 3 below)

Livestock	Amanuel (TLU)	Amanuel TLU Density	Fortu (TLU)	Fortu TLU Density	Abagirja (TLU)	Abagirja TLU Density	Yewel (TLU)	Yewel TLU Density	Total TLU
Calf	43	3.30	34.75	0.48	23	0.66	44.5	1.88	145.25
Cow	197	15.12	243	3.39	143	4.09	222	9.39	805
Ox	124	9.52	128	1.78	181	5.18	118	4.99	551
Horse	60.5	4.64	30.8	0.43	12.1	0.35	34.1	1.44	137.5
Adult Donkey	175.7	13.49	143.5	1.99	46.2	1.32	156.7	6.63	522.1
Adult Sheep	201.5	15.47	188.11	2.62	67.21	1.92	205.14	8.69	661.96
Goat	23.92	1.84	25.35	0.35	13.65	0.39	16.9	0.72	79.82
Chicken	9.074	0.69	8.801	0.12	3.224	0.09	8.593	0.36	29.692
Total									2932.32

Table 3 Tropical Livestock Unit Representation (TLU) and TLU Density per watershed label.

It's therefore preferable to show the distribution by using charts and graphs.



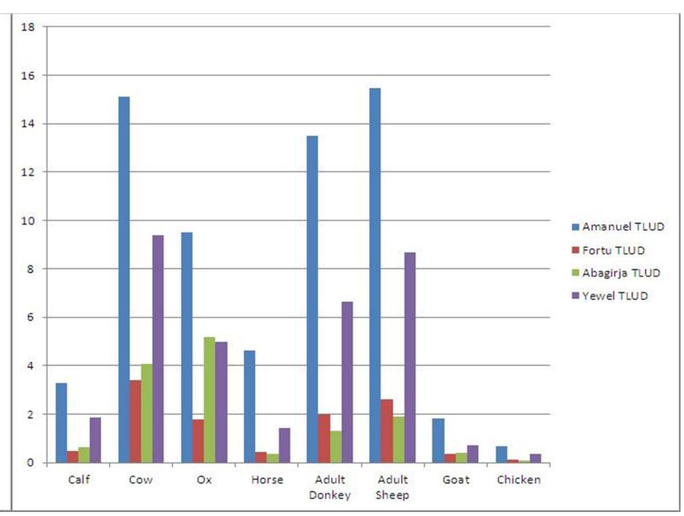
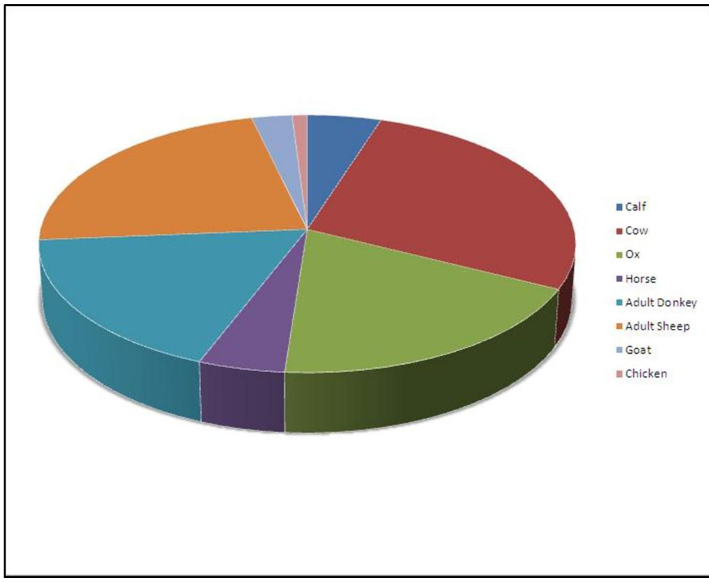


Fig. 10 Graphs showing livestock distribution in TLD (left) and TLU density (right)

Cows, adult sheep, adult donkeys and oxen have the highest TLU, specifically in Fortu, Yewol and Amanuel watersheds. However, Amanual and Fortu have the highest TLU density.



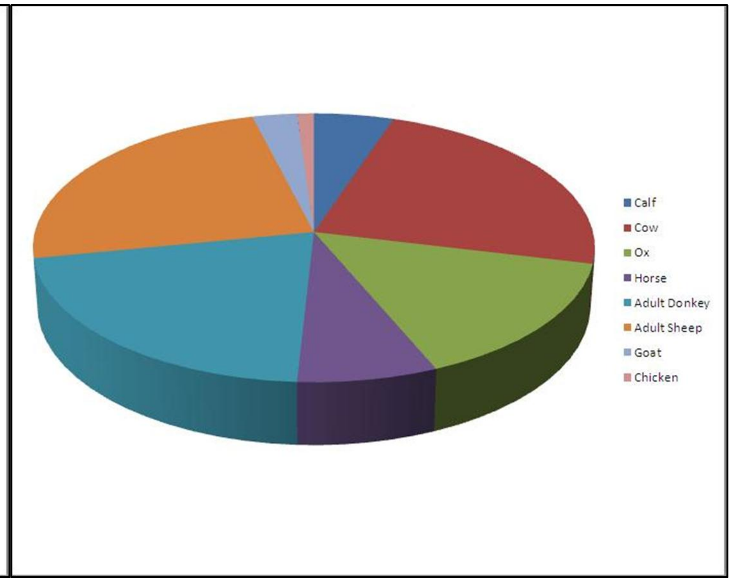


Fig. 11 Pie charts showing total livestock distribution in TLD (left) and TLU density (right) in kabe watershed.

4.8. Agroclamatic zones/altitude

The altitude maps are generated from the 30m DTED and 20m contour map. The elevation of the area ranges from 2020-3840m above sea level. The northern part of the area is relatively higher and it descends down as we go to the south. Therefore, the southern part of the area is relatively flat and very suitable for agriculture as it is reach with fertile soil eroded from the upstream.

The whole area falls in one agroclimatic zone.

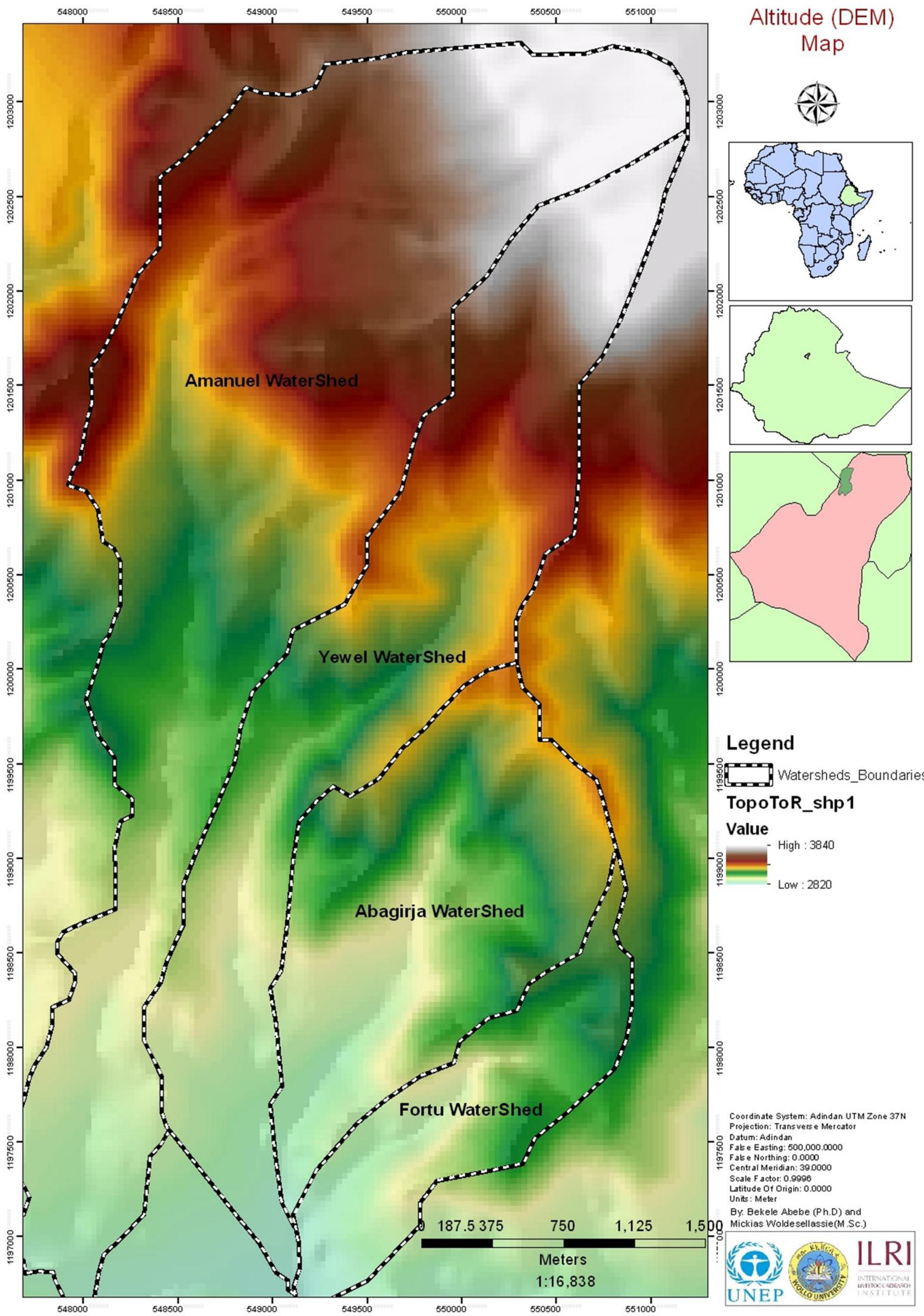


Fig. 12 Altitude map

4.9. Climate change- rainfall and temperature trends/projections

Temperature and rainfall data from Meteorological stations were used to forecast future Temperature and Rainfall of the area. SPSS software was used to manipulate

and model these datasets in order to forecast. This in turn enables to tell about future climatic condition of the area.

A lot of missing values were in the data and Linear Trend Point Method was used to fill this missing values. With modeling these datasets, it was possible to project the temperature and rainfall data of the project area up to 2017. However, since we have too many data gaps, the projection may not be as such reliable. Data ranges of temperature spanning from 1981-2007 and rain fall 1963-2005 was only available from the station data. Thus, coming to 2013, the present year, is by itself a projection. However, as it's mentioned above, projection up to 2017 was done.

Temprature analysis

As it can be seen from the Residual Autocorrelation Function plot (ACF) below, the data passes stationarity test. So, model fitting was followed.

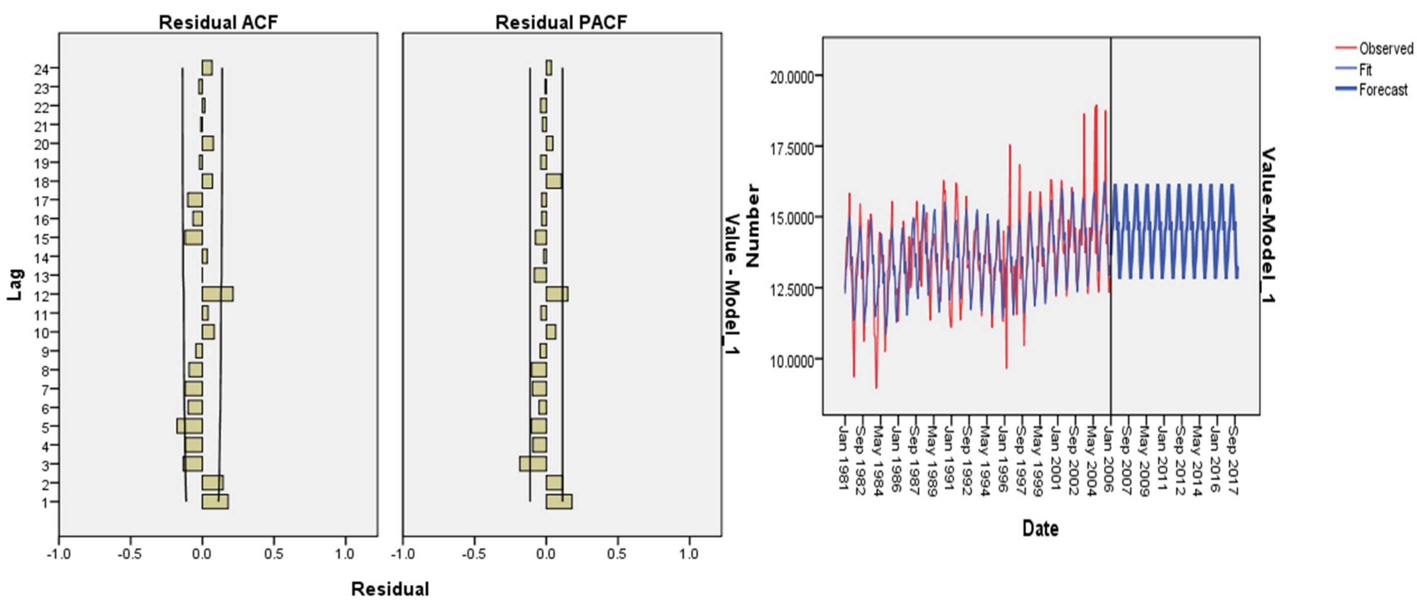


Fig. 12 Residual Correlation Functions and Model Fitting of the Temperature data

The new SPSS version suggests a model based on the behavior and characteristics of the input data. Therefore, during the analysis the Expert Modeler suggested to use Simple Seasonal Time Series Model. Hence, Simple Seasonal Time Series Model is used to model the data.

Model Description

			Model Type
Model ID	Value	Model_1	Simple Seasonal

Table 4. Model Description

As it can be seen in the table below, the model is statistically significant.

Model	Number of Predictors	Model Fit statistics			Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	MAPE	MaxAPE	Statistics	DF	Sig.	
Value-Model_1	0	.548	5.048	38.664	74.674	16	.000	0

Table 5 Description of the Model Fit Statistics

Fig. 13 Temperature Forecasting

Interpretation of the result of this forecast modeling shows the temperature of the area will generally be increasing. This is clearly manifested on Belg, Kiremt and Annual temperature of the area, which agree with the global temperature rise. The rate of the temperature rise, however, exceeds the global trend and a serious action is needed to maintain its climate.

Rainfall Analysis

As we can see again from the Residual Autocorrelation Function (ACF) plot, the data passes stationarity test and hence, model fitting is done.

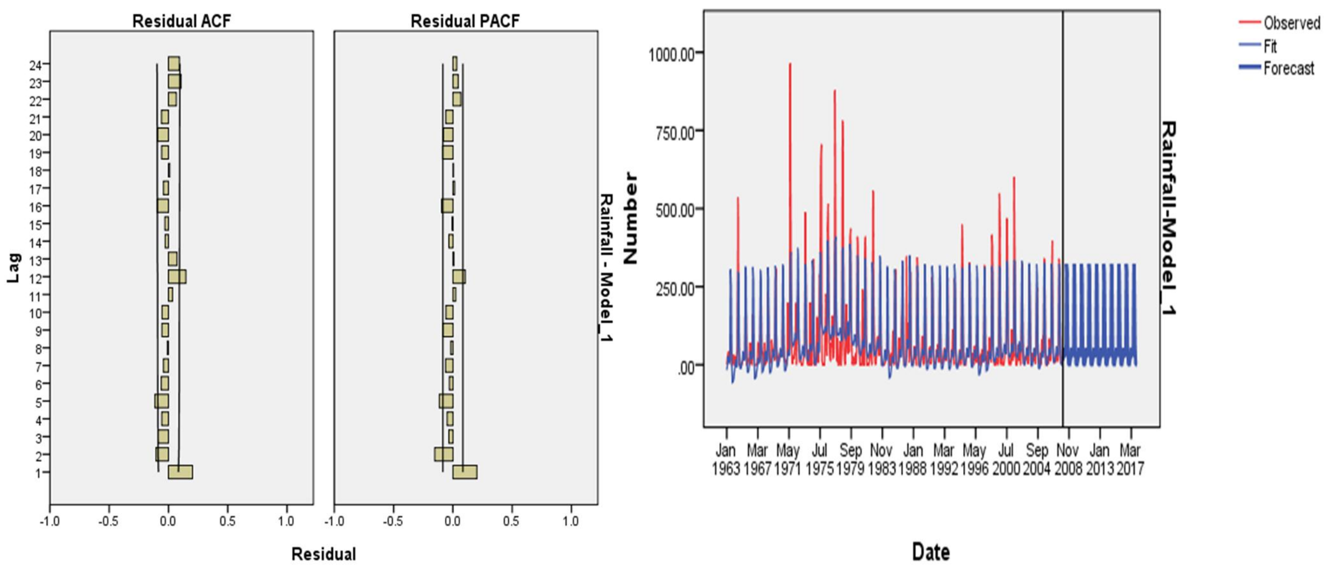


Fig. 14 Residual Correlation Functions and Model Fitting of the Data

SPSS Expert Modeler also suggested Simple Seasonal Time Series Model to use for this data and the model is statistically fit.

Model Description

			Model Type
Model ID	Value	Model_1	Simple Seasonal

Table 6 Description of the Model

Model	Number of Predictors	Model Fit statistics			Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	MAPE	MaxAPE	Statistics	DF	Sig.	
Value-Model_1	0	.548	5.048	38.664	74.674	16	.000	0

Table 7 Description of the Model

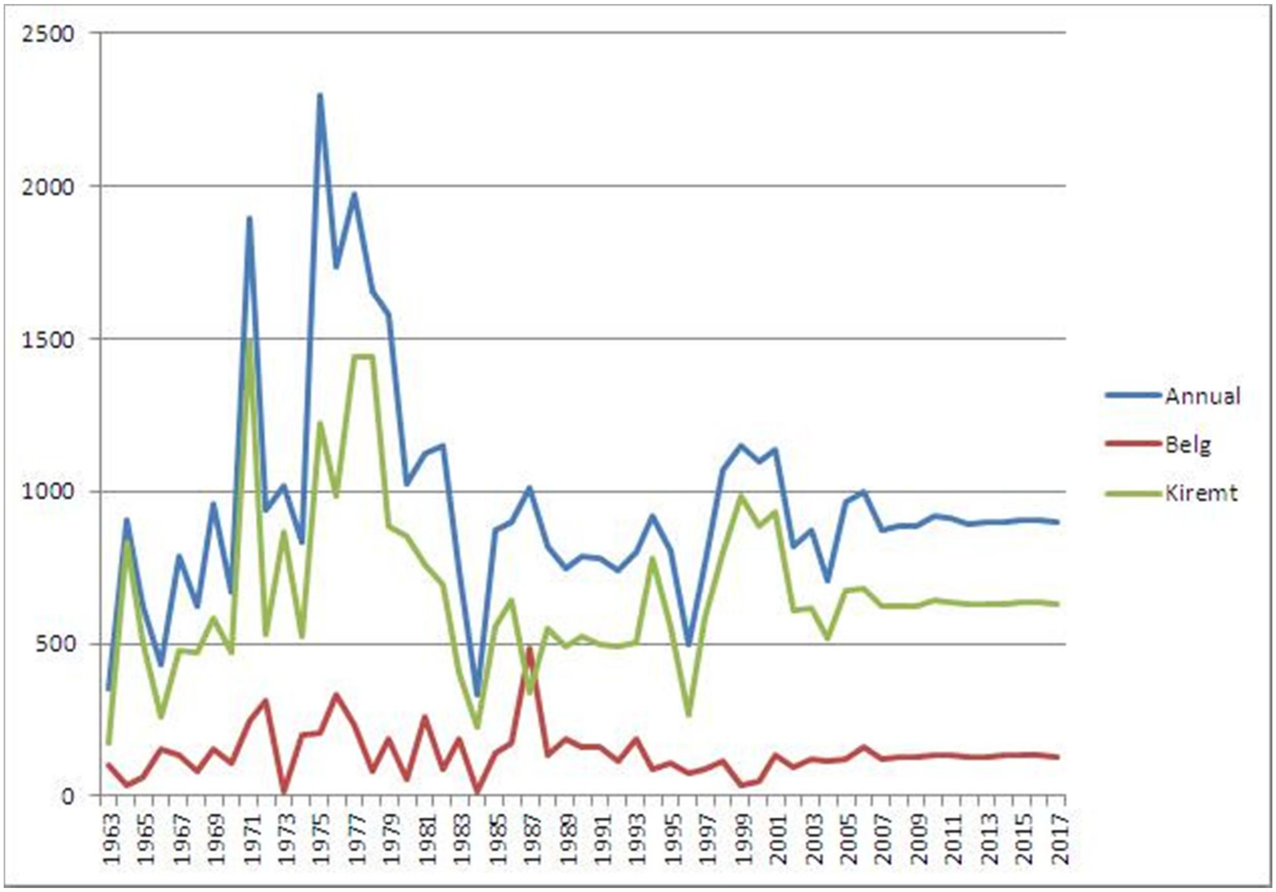


Fig. 15 Rainfall forecasting

Looking just closely into this graph, it depicted the historical droughts of the area. Around 1973/74, there was a severe drought in northern Ethiopia mainly in Tigray and Wollo. It was also affected Gondar and Gojam but mostly known by a name called “Wollo Dirk” locally. Another historical drought was occurred in the area after 10 years in 1984 which is also known locally by “77 Dirk”. Almost 10 years after, there was also a similar drop in rainfall. This reveals that the area has been affected by a serious of severe periodical droughts (i.e. 1974, 1984, 1995, 2004). Though the forecasting is not that reliable due to data gaps, it however still tells a general decrease in rainfall. Therefore, an integrated intervention is a must to tackle the problem in the area.

4.10. Future projections on landuse

The change in Landuse/Landcover is done based on three multitemporal landsat imageries with 14 years interval (1973, 1986 and 2000). Six main Landuse/Landcover types are identified in these mapping. i.e. Agricultural land, Bareland, Grass Land, Scarce Bush, Scarce Shrubs and Shrubs mixed with trees. Based on these mapping, there was no as such a forest record in the area. It probably loses its dense forest before 1973. Agriculture in the area has been taking place since quite a long ago. This mapping was done with an overall average accuracy of 80% and Kappa coefficient of 78%.

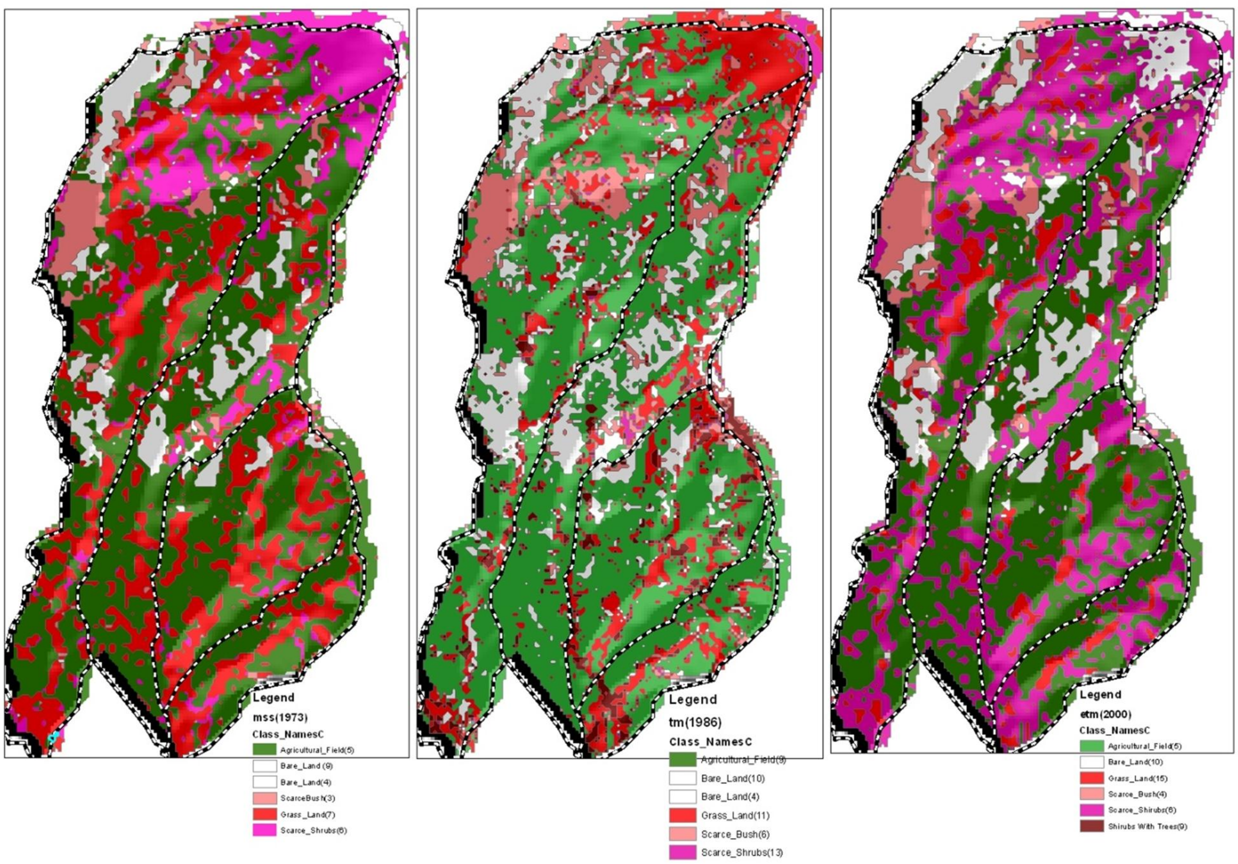


Fig. 15 Landuse/Landcover Maps from 1973(MSS), 1986(TM), and 2000(ETM) Landsat images

As it can be seen on the map, agricultural land (green) is the dominant Landuse/Landcover (LU/LC) unit in the area. Its trend shows a general increase; however, in the 1986 images it has its lowest areal coverage as compared to the other two imageries. This might be resulted due to the severe 1984 drought. On the other hand, the trend of the bare land is increasing starting from the MSS to TM and then to the ETM landsat images. This reveals again the other LC/LU types are converted into a bareland which is not unproductive and very much exposed to land degradation.

	MSS in Km2	MSS in Ha	Tm in Km2	Tm in Ha	ETM in Km2	ETM in Ha	Change b/n MSS/TM in Ha	Change b/n TM/ETM in ha
Agricultural Field	7.93558	793.9154	7.001381	700.3565	8.837777	883.8461	93.558869	-183.489605
Bare_Land	1.416761	141.6532	1.673029	167.2368	2.289623	229.0024	-25.583682	-61.765547
Grass_Land	0.781879	78.17638	1.243128	124.2732	2.953215	295.3137	-46.096788	-171.040534
Scarce_Bush	4.392844	439.2608	0.969009	96.90759	1.403358	140.3381	342.353247	-43.430488
Scarce_Shrubs	1.884106	188.3865	5.524282	552.1265	0.218493	21.84954	-363.73997	530.276957
Shirubs with Trees	0	0	0	0	0.706534	70.65566	0	-70.655656

Table 8 Attribute Table of the Landuse/LandCover map

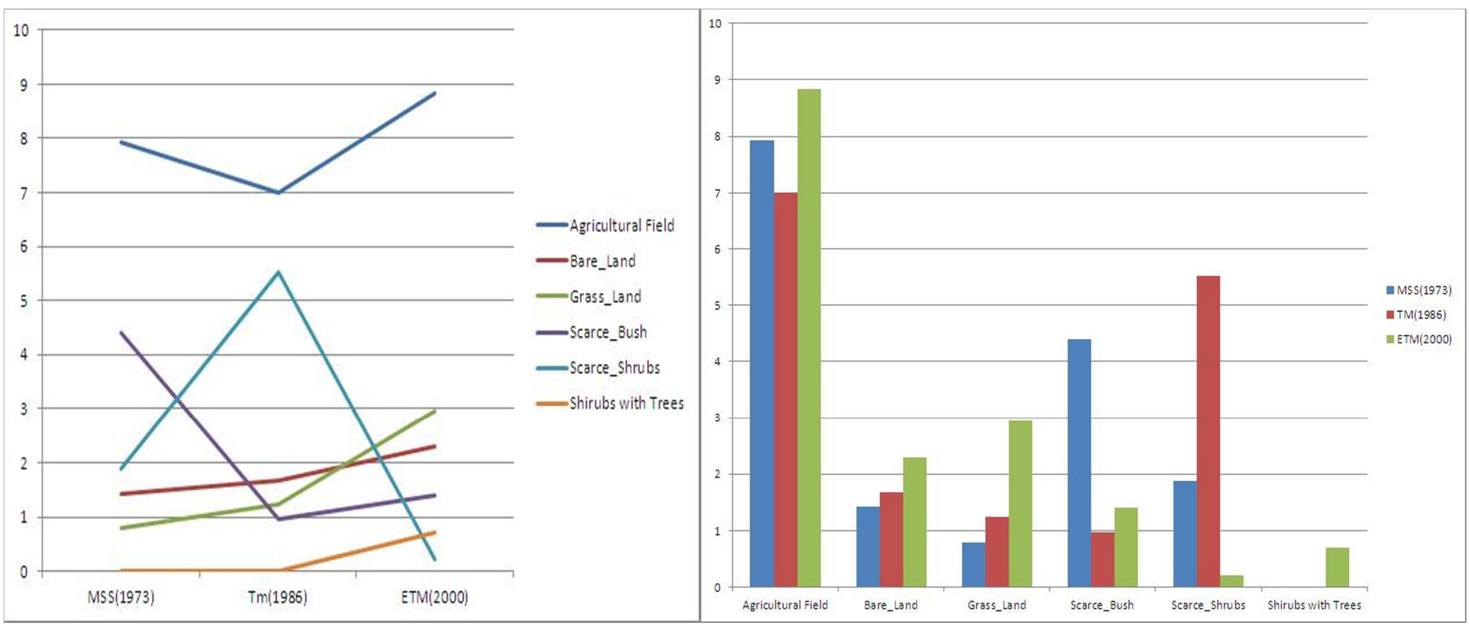


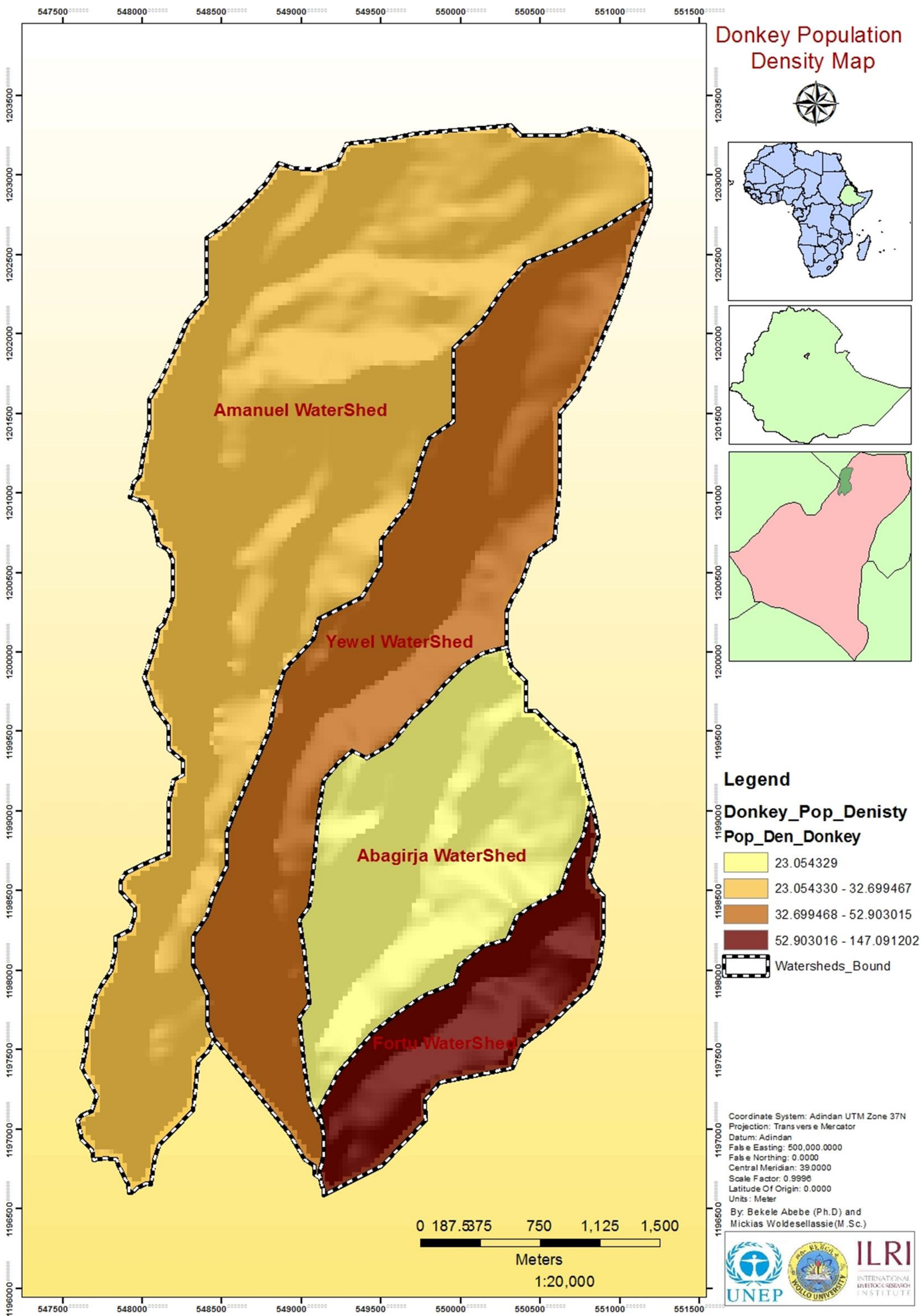
Fig. 16 Landuse/Landcover Trends

The LU/LC trend graphs above also shows that grass land is expanding in the area as the shrub lands are changed into grass land. Moreover, a new artificial tree plantation, specifically eucalyptus, is active in the area since 2000. During the field trip, it was witnessed that marshy spots and springs found dry probably due to a nearby massive eucalyptus planation. Further study is highly recommended regarding this issue in the area before turning the area with eucalyptus LU/LC. Therefore, cares should be taken in order to rehabilitate this area.

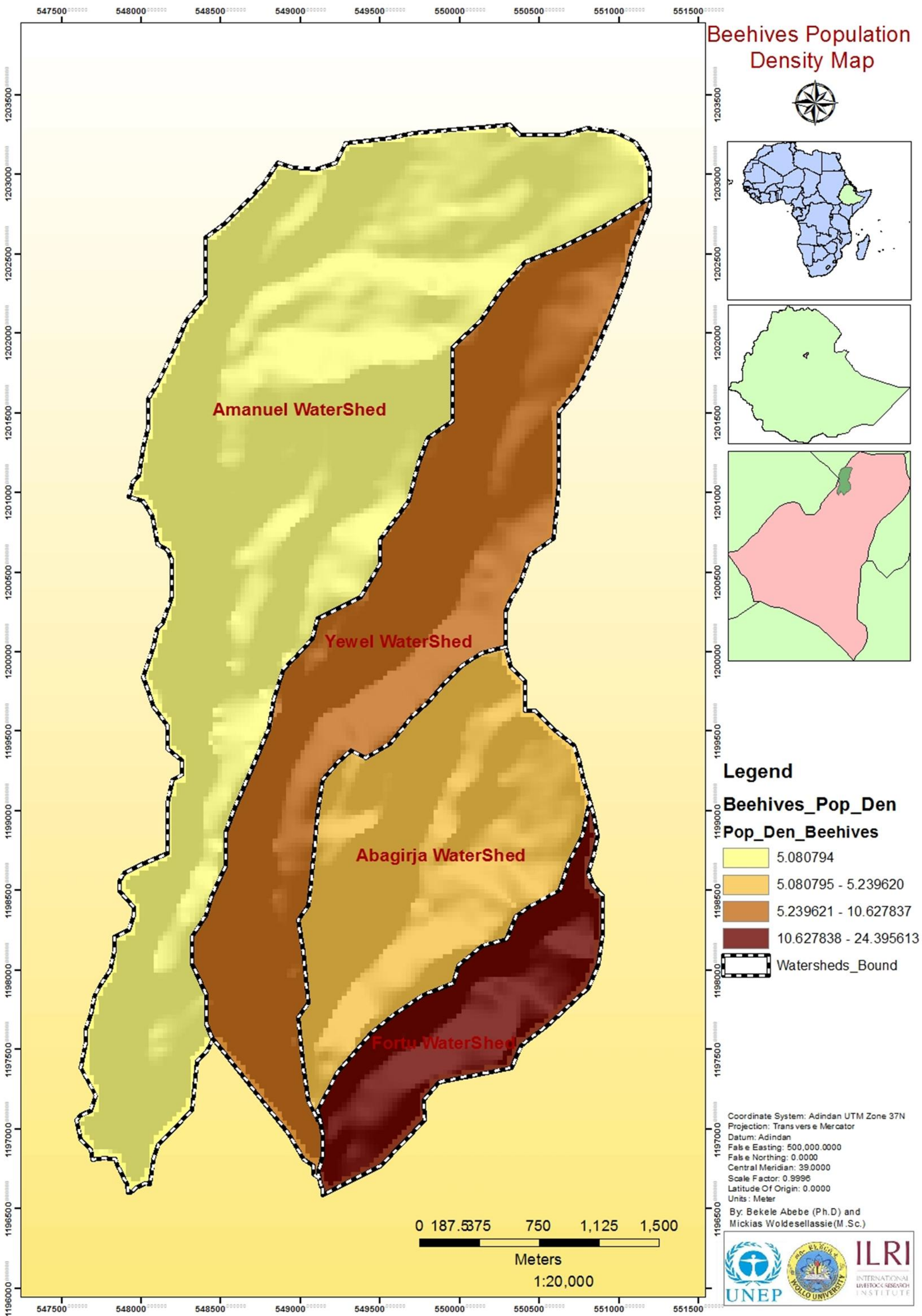
5. Challenges:

The smaller size of the area couples with data gaps was a big challenge to map this watershed. However, we have implemented different methodologies in order to map the area.

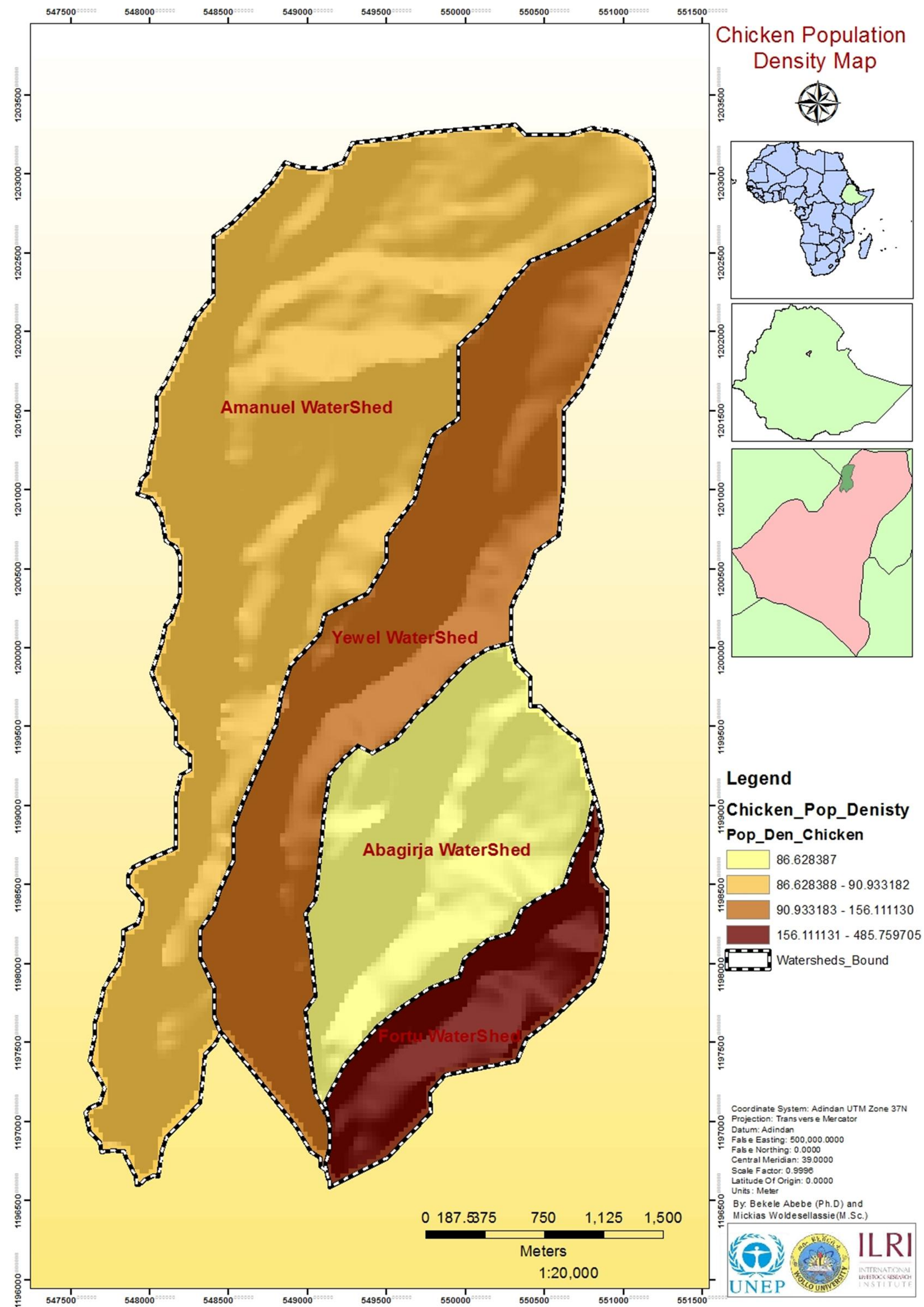
Appendix 1 Donkey population density map at watershed level



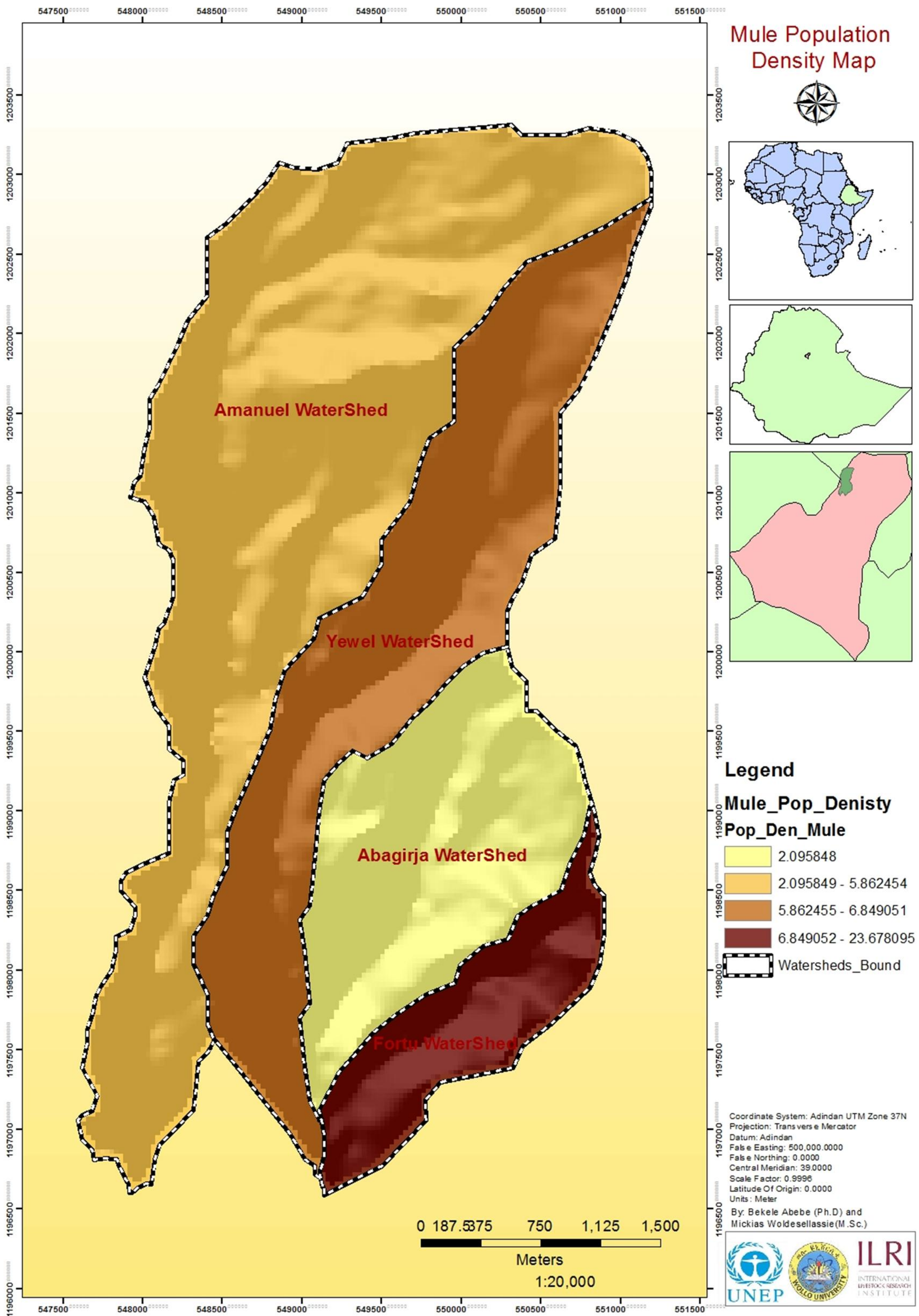
Appendix 2 Beehives Population Density Map at watershed level



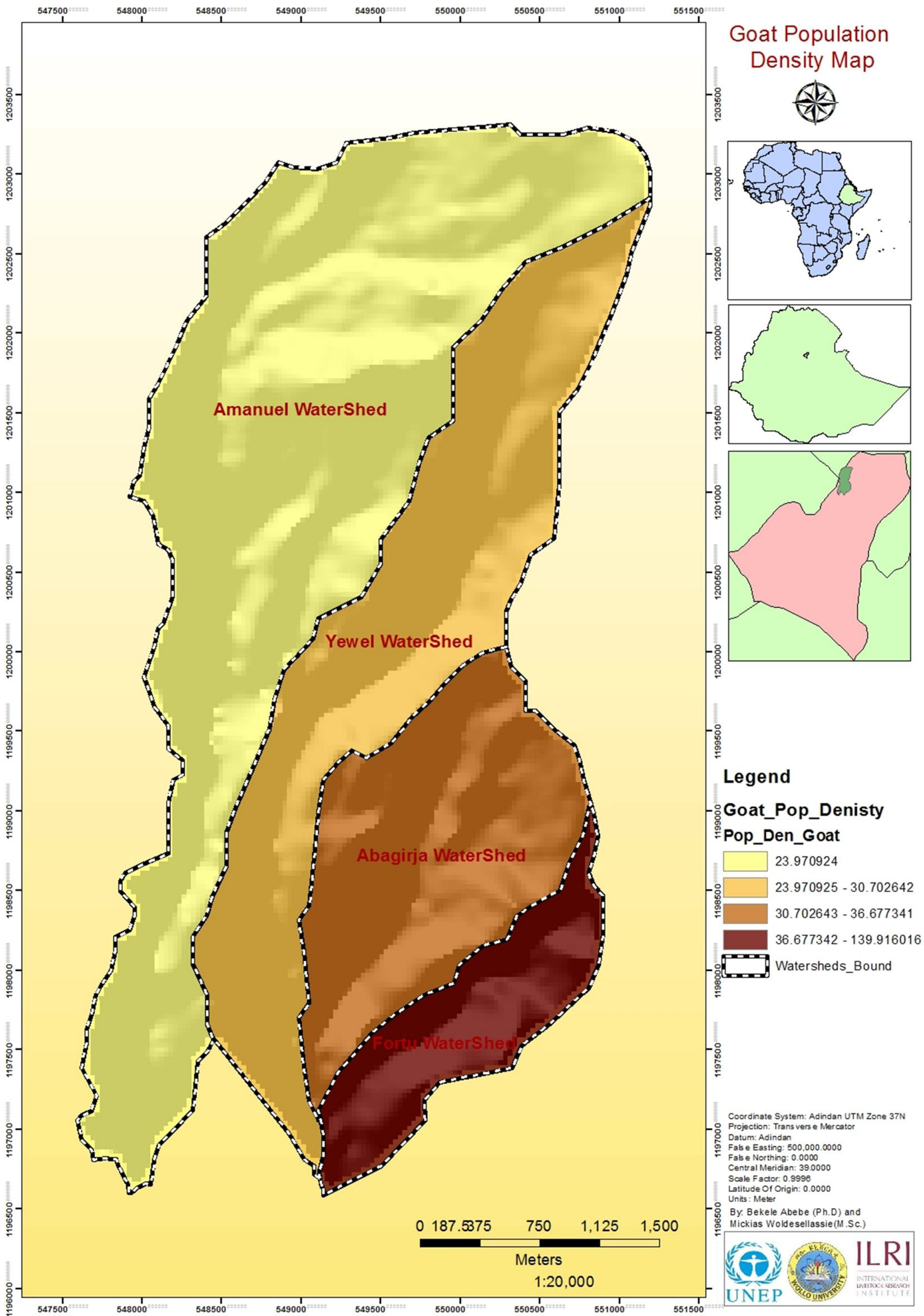
Appendix 3 Chicken Population Density Map



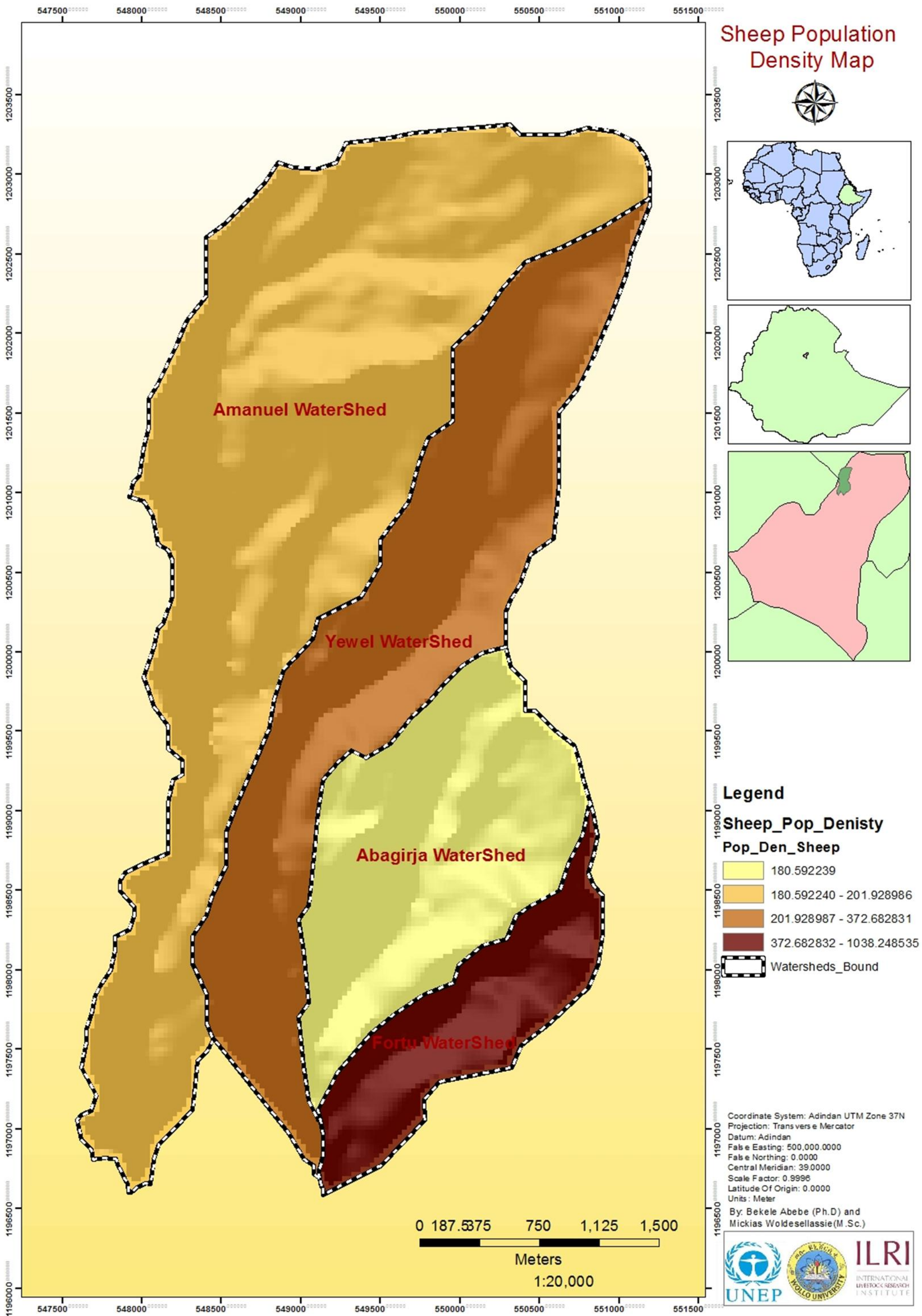
Appendix 4 Mule population density map at watershed level



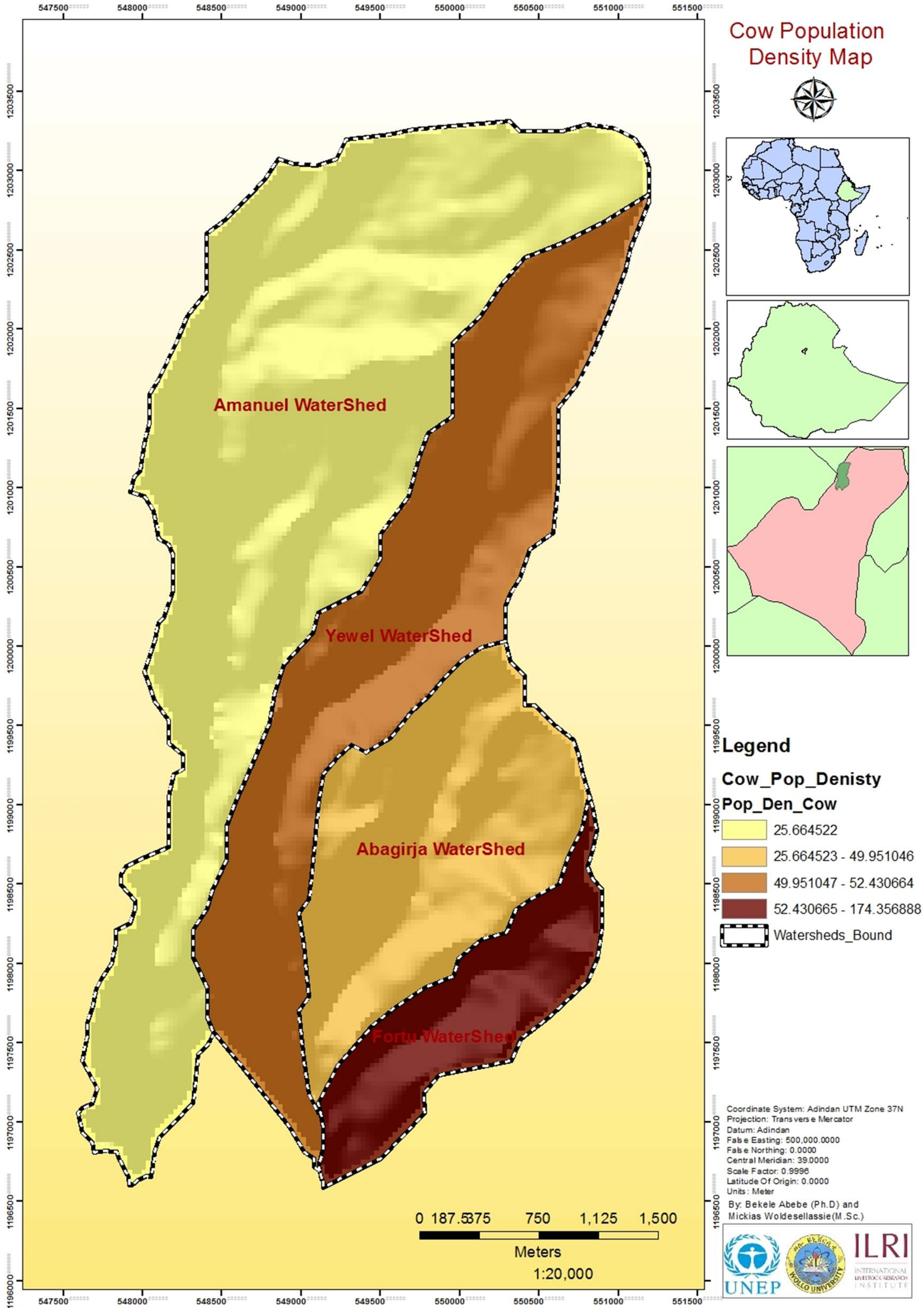
Appendix 6 Goat population map at watershed level



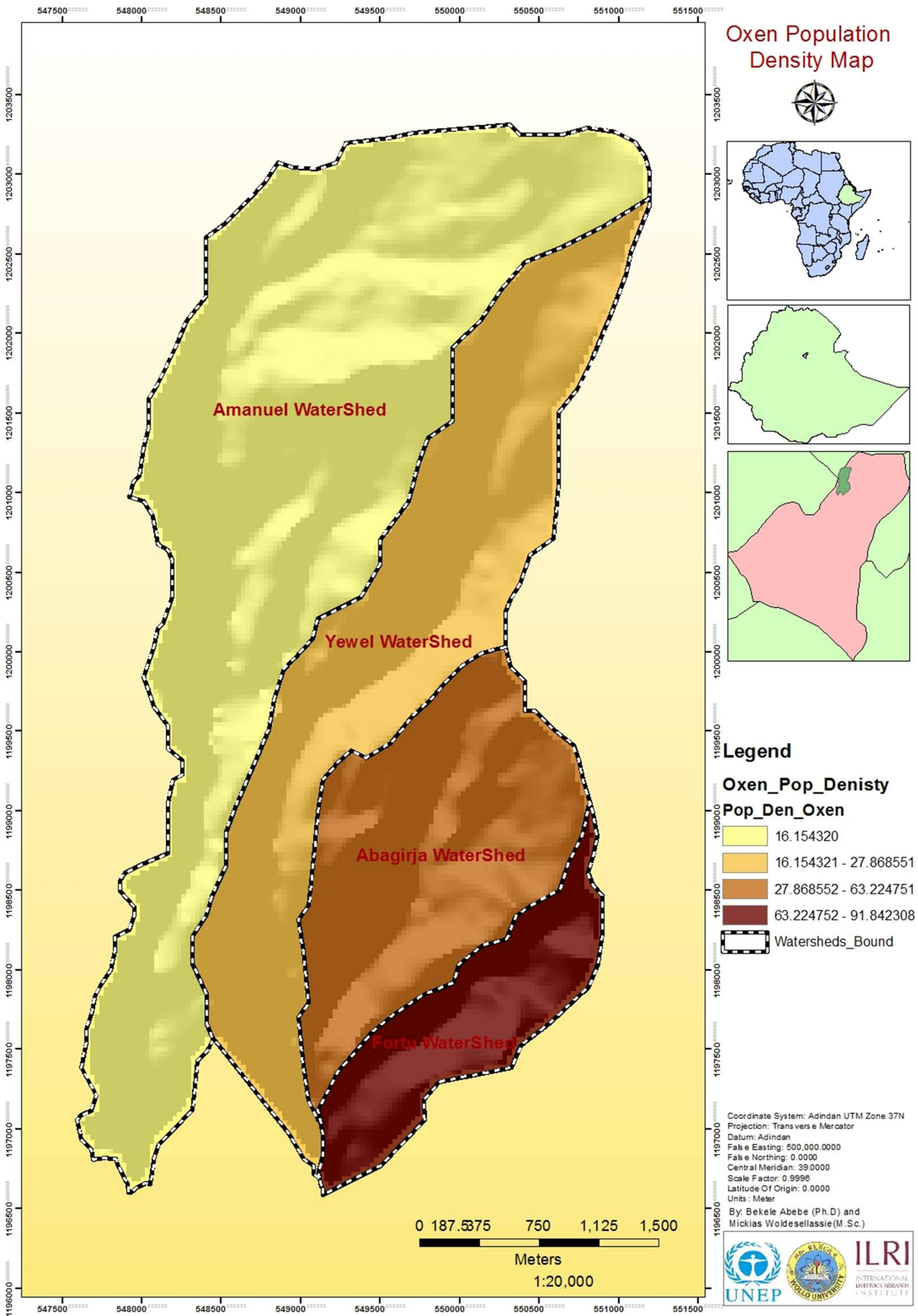
Appendix 7 Sheep Population Density Map



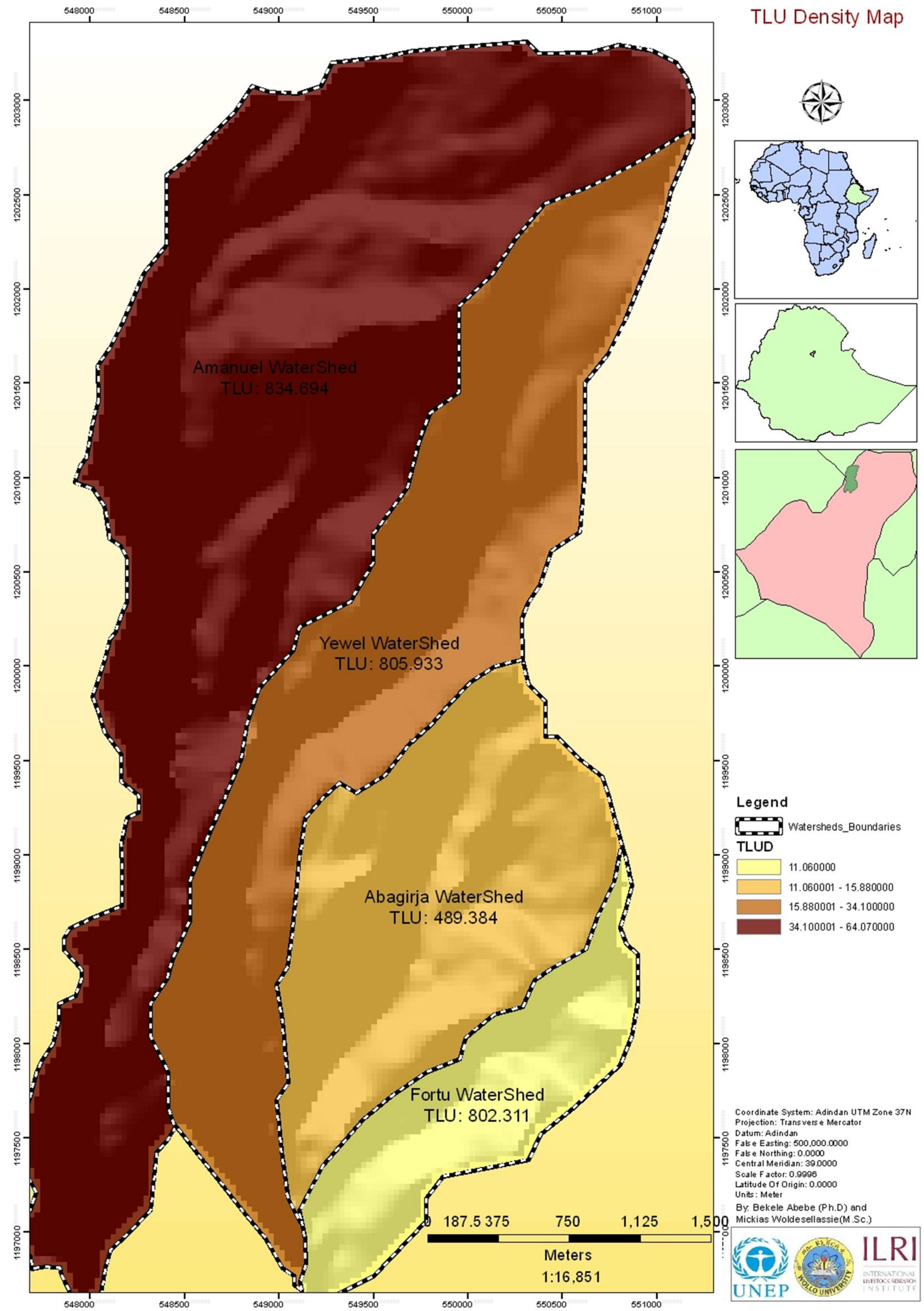
Appendix 8 Cow Population Density Map



Appendix 9 Oxen Population Density Map



Appendix 10 Total TLU (Tropical Livestock Unit) map



Annex1

Station_ ID	Name	F3	X	Y	Z	Status	Remark
YST1	Balfe	Spring	550517	1201369	3280	Developed	
YST2	Ababa Gedel	Spring	550534	1202136	3418	Undeveloped	
YST3	Ababa Gedel	Spring	550211	1201510	3242	Developed	Kulbayne Hunddug well
YST3	Bagan Ager	Spring	549858	1200887	3136	Undeveloped	Handdug well
YST4	Medoch	Spring	550079	1200720	3097	Undeveloped	Along the stream
YST5	Woneshe	Spring	550016	1200530	3076	Undeveloped	Adjucene to the stream
AST1	Ehidaw	Spring	550531	1202779	3548	Undeveloped	Bulbul Ager
AST2	Aba Moha Ager	Spring	550323	1202734	3513	Undeveloped	
AST3	Argo Ager	Spring	549764	1203181	3390	Undeveloped	
AST4	Argo Ager	Spring	549427	1202678	3274	Undeveloped	
AST5	Jarso Ager	Spring	548807	1201758	3192	Developed	
AST6	Jarso Ager	Spring	548879	1201073	3072	Developed	Jale Chefe
AGST1	Aba GirjaW 1	Spring	550326	1199319	3036	Developed	Developed by Wollo Uni and has water through out the year
AGST2	Aba GirjaW 2	Spring	550255	1198941	2982	Undeveloped	Used for irrigation (Vegi + Apple)
AGST3	Aba GirjaW 3	Spring	550169	1198929	2971	Hand Dugwell	Used for irrigation (Vegi + Apple)
AGST4	Aba GirjaW 4	Spring	550037	1198583	2935	Developed plus Night Storage	At the outlets of Asta River and on the east bank of this river a developed spring sealed with concrete is also available
AGST5	Aba GirjaW 5	Spring	549638	1198145	2983	Hand Dugwell	Developed by Wollo Uni and has water pump
AGST6	Aba	Spring	549590	11982	288	Hand	Developed by Wollo Uni and has

	GirjaW 7			65	9	Dugwell	water pump for one family
AGST7	Aba GirjaW 8	Spring	549487	1198222	2882	Shalow Well	Unused
AGST8	Aba GirjaW 9	Spring	549339	1197573	2974	Hand Dugwell	
FST1	FortuW 2	Spring	550126	1197787	2904	Developed	
FST2	FortuW 3	Marshy Spot	550447	1197983	2947	Marshy Spot	
FST3	FortuW 1	Night Storage	549892	1197573	2884	Dam	Developed by Woreda Agricultural Bureau
M1		Spring	549332.1	1197974	0	Hund Dugwell	
M2		Diversion Site	549176.4	1197418	0	Diversion Site	
M3		Diversion Site	549452.1	1197947	0	Diversion Site	
M4		Spring	549616.7	1198121	0	Hund Dugwell	
M5		Spring	549594.3	1198262	0	Hund Dugwell	
M6		Spring	550034.3	1198586	0	Diversion Site	